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UNIVERSITY OF ALBERTA

THE LATE QUATERNARY HISTORY OF RUSSELL ISLAND, N.W.T.

by

DAVID E.C. GREEN

(C)

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

GEOGRAPHY

EDMONTON, ALBERTA

Fall 1986

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Late Quaternary History of Russell Island, N.W.T. submitted by David E.C. Green in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date May 6/86

Abstract

The late Quaternary history of Russell Island was investigated by mapping its surficial geology and reconstructing the pattern of postglacial emergence. The surface materials are divided into 10 genetic units. Till covers 53 percent of the island; rock 25 percent; raised marine beaches 20 percent and glaciofluvial, alluvial and other marine sediments cover the remaining area.

Like other parts of the central Arctic, older Quaternary glaciations are recognized by the widespread dispersal of crystalline erratics northward from the mainland onto Russell Island. During the maximum of the late Wisconsin, the M'Clintock Ice Divide, located immediately west of Russell Island, dispersed ice throughout the central Arctic. Striae indicate that ice flowed eastward from the M'Clintock Ice Divide across Russell Island. This dispersal pattern spread fine-grained calcareous material over the clastic bedrock of the eastern part of the island.

Deglaciation commenced about 11,300 BP in the central Arctic. During this time, the centre of ice dispersal shifted with respect to Russell Island, first to the east and then to the south. This resulted in the formation of striae that record deglacial flows which moved north and northwestward across Russell Island. The northwestward deglacial flow was particularly erosive, re-distributing the original carbonate materials and forming features such as roches moutonnées and flutings found on the eastern uplands. The final ice margin of the deglacial flows deposited the Russell Island End Moraine and a kame complex in the central uplands of Russell Island.

Sixteen radiocarbon dates on in-situ bone, driftwood and shells collected from raised beaches and marine silt provide an envelope of the island's postglacial emergence. A minimum date for deglaciation on Russell Island is provided by marine shells dated at 9360 +/- 150 BP (GSC-3994). However, projections of marine limit dates from the adjacent coast of Prince of Wales Island suggest that Russell Island was ice-free between 11,000 and 9,800 BP. The uppermost shorelines observed on Russell Island vary from 108 m asl on the west coast to 96 m

asl on the east coast. The western shoreline is significantly lower than expected, being 80 m below the marine limit on Donnett Hill, Prince of Wales Island, only 12 km to the south. The uppermost shoreline in eastern Russell Island is near the expected elevation, based on the projection of shorelines from Cape Hardy, northern Prince of Wales Island. The initial rates of emergence on western Russell Island also depart from that at Donnett Hill, taking a shallower form in the upper part of the emergence envelope whereas both areas show similar emergence after 7000 BP.

The most likely explanation for the anomalously low emergence on western Russell Island is that marine limit was not observed due to the small areas available at its expected elevation (ca. 170 m asl). There is also the added possibility that pervasive landfast sea ice accompanied deglaciation, hindering the formation of recognizable shorelines. The Quaternary history of Russell Island is discussed in relation to previous and ongoing research in the central Arctic.

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Many people have contributed to this study. The project was initiated and directed by Dr. A.S. Dyke of the Geological Survey of Canada. Dr. Dyke provided helpful revisions of the early drafts and encouragement throughout. Further advice, guidance and invaluable criticism was given by my supervisor, Dr. J.H. England. I am also appreciative of the constructive criticism by Dr. B. Rains and Dr. N. Rutter at the thesis defence.

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1. INTRODUCTION

1.1 Nature of the Study

In recent years a controversy has developed concerning the configuration of ice sheets during the Late Wisconsinan glacial maximum. The argument surrounds two opposing models which propose a minimum versus a maximum ice cover during the last glaciation (Ives, 1978). These models are most contentious at the northern margin of the Laurentide Ice Sheet in the Canadian Arctic.

The purpose of this study is to investigate the late Quaternary history of Russell Island, immediately offshore from the northernmost coast of Prince of Wales Island (Fig. 1.1). Russell Island is ideally located for refining the history of the north-central Laurentide Ice Sheet and the dynamics of the recently identified M'Clintock Ice Divide to the southwest (Dyke et al.,1982). The principal objective involved mapping the surficial materials, including major landforms, and erosional indicators of past ice movement. Furthermore, an emergence curve showing the sea level history is used to determine the amount of glacioisostatic unloading and the timing of deglaciation. The general pattern of emergence is described and evaluated with reference to other areas at the northern periphery of the Laurentide Ice Sheet. Emergence rates and marine limit elevations are compared in detail to those across Baring Channel on northern Prince of Wales Island. This study is associated with other ongoing projects researching the Quaternary history of the central Arctic, particularly those by A.S. Dyke (Geological Survey of Canada) and T. Morris (University of Alberta) on neighbouring Prince of Wales Island.

1.2 Previous Studies

In this section, a historical review of previous research on Quaternary glaciations and sea level fluctuations in the central Arctic is presented. Field techniques and interpretations are specified for each study. The latest views concerning Late Wisconsinan ice extent are featured because they directly pertain to the objectives of this study.

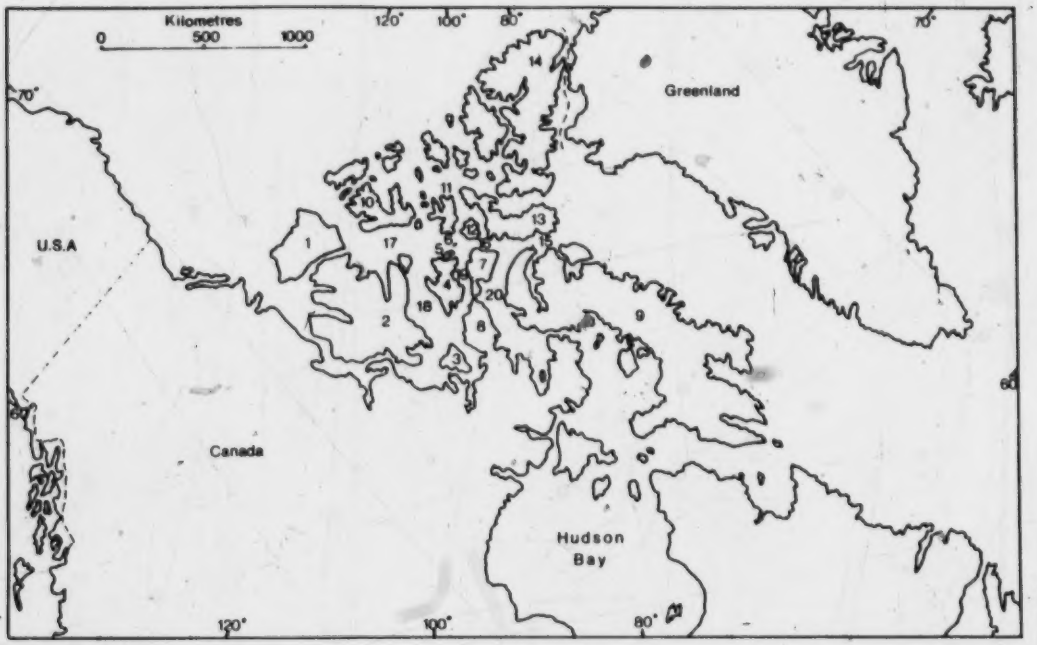


Figure 1.1. Location map of northern Canada with place names used in text: 1.Banks I.,2.Victoria I.,3.King William I.,4.Prince of Wales I.,5.Russell I., 6.Lowther I.,7.Somerset I.,8.Boothia Penin.,9.Baffin I.,10.Melville I., 11.Bathurst I.,12.Cornwallis I.,13.Devon I.,14.Ellesmere I.,15.Lancaster Sound,16.Barrow Strait,17.Viscount Melville Sound,18.M'Clintock Channel, 19.Peel Sound,20.Gulf of Boothia.

1.2.1 Mapping

The earliest field reconnaissance of glacial features in the Arctic Archipelago was undertaken by Washburn (1947) who concluded that there had been widespread glaciation across King William, Victoria and southern Banks islands (Fig. 1.1). Jenness (1952) accepted Washburn's observations and identified landforms from aerial photographs to map the limit of continental glaciation throughout the eastern and central Arctic. He tentatively concluded that continental ice managed to invade only the southern Arctic Archipelago. The landforms in the northern uplands of Banks, Prince of Wales and Somerset islands "closely resembled" very mature landforms found on the islands north of Viscount-Melville Sound which were considered to have been beyond the limit of continental glaciation during the Wisconsinan (Jenness, 1952, p.945). This conclusion was based on the development of the drainage patterns together with the absence of lakes and large scale glacial deposits. Jenness (1952) also noted that there was isolated evidence of former local ice caps north of Viscount-Melville Sound.

These initial observations were followed by fieldwork in the central Arctic by Craig and Fyles (1960). They also concluded that "... on Somerset and Prince of Wales Islands, little evidence is available regarding the extent of Laurentide Ice, of regional ice from a more northerly source, and of local ice caps. The Laurentide boundary is tentatively placed between southern lowlands and northern highlands that are reported to bear only indefinite evidence of glaciation" (Craig and Fyles, 1960, p.2).

Following the fieldwork of Operation Prince of Wales, Craig (1964, p.4) revised the initial hypothesis, stating that the "northern highlands were overridden by the Laurentide (continental) Ice Sheet at the same time as the region to the south". He concluded this on the basis of: a discontinuous rubbly till covering the highlands; extensive Precambrian erratics; and isolated deposits of thick ground moraine, kames and lateral meltwater channels. On the other hand, Bird (1967), who conducted fieldwork during the same period, concluded that the moraines and abandoned channels located across the waist of Prince of Wales Island represented the limit of Laurentide Ice and that much of the highlands of northern Prince of

Wales Island and of necessity all of Russell Island were ice-free during the last glacial maximum. Bird (1967) also surmised that there was an independent ice cap on northern Somerset Island which coalesced with Laurentide Ice to the south.

Farther to the west, Fyles (1963) found extensive ice flow features oriented westward to northwestward across Victoria Island. There, the Late Wisconsinan ice had thinned to the west and during deglaciation withdrew towards the southeast. Fyles (1965, 1967) proposed that Laurentide ice had extended across Parry Channel depositing the Winter Harbour moraine on southern Melville Island during the late Wisconsin.

Quaternary research in the central Arctic was enhanced in the mid-1970's with the need for terrain analysis for proposed northern pipeline routes. Boydell et al. (1975a,b) used aerial photographs and helicopter surveys to categorize the terrain of Boothia Peninsula and the northern District of Keewatin. Netterville et al. (1976a,b) compiled a similar inventory of surficial materials, landforms, and basic terrain types for Somerset and Prince of Wales islands while Barnett et al. (1976) produced a terrain inventory of Bathurst, Cornwallis and adjacent islands (Fig. 1.1)

Boydell et al. (1975a,b) concluded that the scattered till veneers and widespread ice-moulded bedforms were evidence of extensive late Wisconsin glaciation on Boothia Peninsula. These glacial landforms indicated a northeastward flow from a dispersal centre in central Keewatin. Netterville et al. (1976 a, b) and Barnett et al. (1976) both identified two phases of glaciation over the region. The earliest phase was most pervasive and left an extensive distribution of Precambrian erratics. Barnett et al. (1976) found "fresh" till and northeastward striae on Lowther Island and therefore surmised that Laurentide ice extended at least to a point between Lowther and Cornwallis Islands (Fig. 1.1) during the latest phase. Netterville et al. (1976 a,b) concluded that the second glaciation was Late Wisconsinan and that its configuration was consistent with the previous views of Craig and Fyles (1960) and Bird (1967), who restricted Laurentide ice to the southern lowlands of Prince of Wales and Somerset Islands. However, contrary to Bird (1967), they did not observe conclusive evidence for an

independent ice cap, stating that: "a large portion of Somerset Island was free of actively eroding glacier ice during the phase 2 maximum" and the deeply weathered terrains of northern Somerset Island were due to "long periods of subaerial exposure" (Netterville et al., 1976b, p.153.)

More detailed mapping of surficial materials on Somerset Island and Boothia Peninsula continued during the late 1970's. There, A.S. Dyke (1978,1979 a,b) reconstructed the regional glacial and sea level history and increased the data-base on permafrost and till characteristics. This research revealed new insights concerning ice sheet configurations in northern Canada during the late Wisconsin maximum, particularly the ice dispersal from the previously unrecognized M'Clintock Ice Divide. Consequently, Dyke et al. (1982) joined Shilts et al. (1979) and Andrews and Miller (1979) in challenging the widely accepted theory of a single domed ice sheet over Hudson Bay (Flint, 1943; Denton and Hughes, 1981) arguing the case for as many as five coalescent ice domes or dispersal centres: the M'Clintock, Foxe, Labrador, Hudson and possibly Caribou domes (Fig. 1.2). This multidome theory was based on field evidence of ice flow patterns, till composition, late glacial landforms, postglacial emergence and free-air gravity anomalies (Dyke et al., 1982).

Dyke's fieldwork in the central Arctic has so far culminated in two regional reports; The Quaternary Geology of Somerset Island (Dyke, 1983); and The Quaternary Geology of Boothia Peninsula and northern District of Keewatin (Dyke, 1984). Dyke (1983) also concluded that the dispersal of Precambrian erratics indicated an early, extensive glacial episode. He postulated that this glaciation occurred during the early Wisconsin based on a glaciomarine delta (180 m asl) above the Holocene marine limit (145 m asl) which contained driftwood dated >38,000 BP (GSC-2542), south of Cresswell Bay, Somerset Island. Dyke also identified a lengthy period of weathering on Somerset Island which produced widespread, mature periglacial landforms, colluvium and residual soils. He could not ascertain the absolute ages of the earliest glaciation or the advanced weathering; for example, if the ice of the earliest glaciation was cold-based and non-eroding, the pre-existing surface could have been left

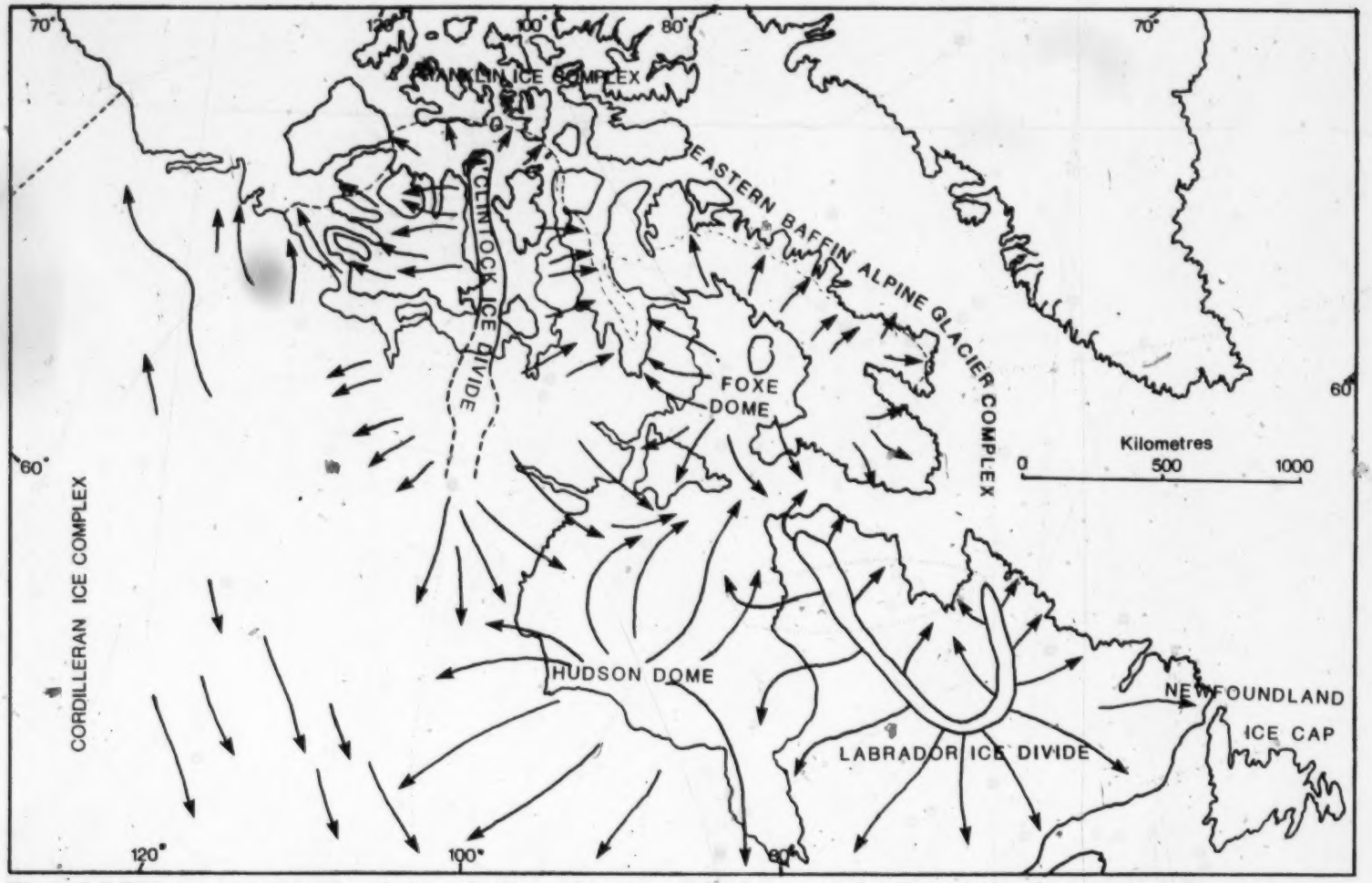


Figure 1.2 Structure and dynamics of the main dispersal centres of the Laurentide Ice Sheet during the late Wisconsin maximum showing ice divides and flow patterns. Adapted from Dyke et al., 1982, p.8.

relatively undisturbed. Therefore, the relationship between the extensive glaciation and the weathered terrain remains uncertain. Evidence of pre-"classical" Wisconsin episodes is not well preserved on Boothia Peninsula except at bluffs in the Pasley River Valley where a stratigraphic sequence with several glacial and marine beds is exposed (Dyke, 1984; Dyke and Matthews, in press).

The present terrain of Somerset Island and Boothia Penisula are largely the product of the last glaciation. Dyke (1983, 1984) compiled the surficial mapping of glacial landforms and till sheets in order to reconstruct the M'Clintock Dome in the central Arctic during the late Wisconsin. The details of his reconstruction are presented at the end of this chapter.

More recently, Hodgson et al. (1984) published their study of the Quaternary geology of Melville Island, north of Parry Channel (Fig. 1.1). They mapped four distinct tills that resulted from separate, northward advances of Laurentide ice. The last advance (Late Wisconsin) deposited the Winter Harbour till which overlapped the Bolduc till and associated late Pleistocene marine sediments on the southeast coast of Dundas Peninsula. Hodgson et al. (1984) concluded that the Winter Harbour till was deposited by a floating ice shelf (the Viscount Melville Sound Ice Shelf) which extended northwestward from the M'Clintock Dome and grounded on the south shore of Melville Island as well as Bathurst and Byam Martin islands (Fig. 1.1). The Winter Harbour till was believed to be bracketed by C^{14} dates on marine shells of 10,340 +/- 150 and 9700+/- 150 BP but recently, dates from northern Prince of Wales Island suggest that the Viscount Melville Sound Ice Shelf probably existed between about 11,300 and 11,000 BP (Dyke, in press b).

1.2.2 Sea Level Studies

The first investigations of Quaternary sea levels in northern Canada were conducted by Low (1896), Bell (1898) and Tyrell (1898). These early studies concerned raised marine sediments and features surrounding Hudson Bay and were initiated in response to research previously conducted in Britain (Jamieson, 1865, 1882) and eastern North America (deGeer,

1892, Upham, 1896). By the early twentieth century, the concept of glacioisostatic adjustments became well established. Fairchild (1918) mapped marine limit elevations and projected the pattern of postglacial emergence in northeastern North America. This work was later extended by Daly (1934) who noted that marine limits appeared to rise in elevation towards Hudson Bay. Flint (1943) used this information to formulate the single ice dome theory for the same area.

Since the development of radiocarbon dating (Libby, 1946), studies of postglacial emergence have become increasingly refined. Local shoreline elevations were surveyed and dated using in-situ organic material. With this data, the rate of glacioisostatic emergence (elevation/time) was plotted as a curve of emergence. Farrand (1962) compared these uplift curves from across the Arctic and was able to isolate several centres of glacial loading. He suggested that the highest point of submergence, the elevation of marine limit, was a function of ice thickness, deglacial history and eustatic sea level changes.

Regional isobase maps have also been employed to illustrate the pattern of postglacial emergence. Isobases are lines connecting points of equal emergence in equal amounts of time and they indicate the tilt of former water planes. Isobases generally ascend in elevation towards the former centre of glacial loading. Early isobase maps were produced for such areas as Labrador (Loken, 1962; Matthews, 1966), eastern Baffin Island (Ives, 1964; Andrews, 1967, Andrews et al., 1970), Hudson Bay (Lee, 1962; Craig, 1969) and the central Arctic (Bird, 1967). With the expanding research on sea level history and the amount of postglacial emergence, widespread dates on marine limit became available. Prest (1968) compiled these dates and was able to map a chronological sequence of deglaciation over Canada.

Andrews (1970) provided a synthesis of postglacial rebound in the eastern Canadian Arctic. He indicated that a main problem at that time was that researchers applied different eustatic sea level corrections to their emergence curves. He used Shepard's(1963) world sea level curve in a mathematical model of emergence which employed a exponential decline in the rate of emergence from a specific marine limit elevation and time. The model was used successfully to predict emergence in western and eastern Baffin Island as well as Hudson Bay (Andrews,

1970).

Recent geophysical studies now suggest that a worldwide eustatic sea level correction is unrealistic. For example, Walcott's (1972) model predicted that land would emerge in areas that were formerly depressed by a glacial load and submerge in areas peripheral to that former ice margin. This was due to the flow of viscous mantle from beneath the peripheral area back into the previously depressed zone. Furthermore, extra-glacial areas will have a unique sea-level history due mostly to the non-uniform, hydroisostatic deformation of the ocean basins (Walcott, 1972).

Several numerical calculations have been used to model the rheological responses of the earth to glacial loading and unloading (Farrell and Clark, 1976; Clark, 1976; Clark et al., 1978). These models endeavored to predict changes in sea level during and after deglaciation. Areas such as the central Arctic which were covered by ice during the last glaciation display the greatest amount of emergence due to more significant glacioisostatic recovery of the geoid and the removal of the gravitational attraction between the ice and water (Farrell, 1972; Clark, 1976). Because relative sea level changes with respect to the distance beyond a former ice margin it is apparent that there is not a single or worldwide "eustatic" curve and the practice of correcting emergence curves has been abandoned. Rheological models of glacioisostatic loading and unloading have led to a greater understanding of past ice sheets because they have shown that the elevation, rate and timing of the resulting emergence reflect glacial and deglacial conditions.

In the central Arctic, Dyke (1983,1984) has reconstructed the pattern of postglacial emergence based on radiocarbon dates obtained on shorelines containing marine shells, driftwood and whale bones. Emergence curves and marine limit profiles from coastal areas of Somerset Island and Boothia Peninsula demonstrate greater amounts of emergence towards the west, indicating thicker ice in that direction. Dyke (1984) subsequently drew isobases on the 9300 BP shoreline in the central Arctic which outline a ridge of postglacial emergence that , in turn, records the unloading of the M'Clintock Dome (Fig. 1.3). The effect and demise of the

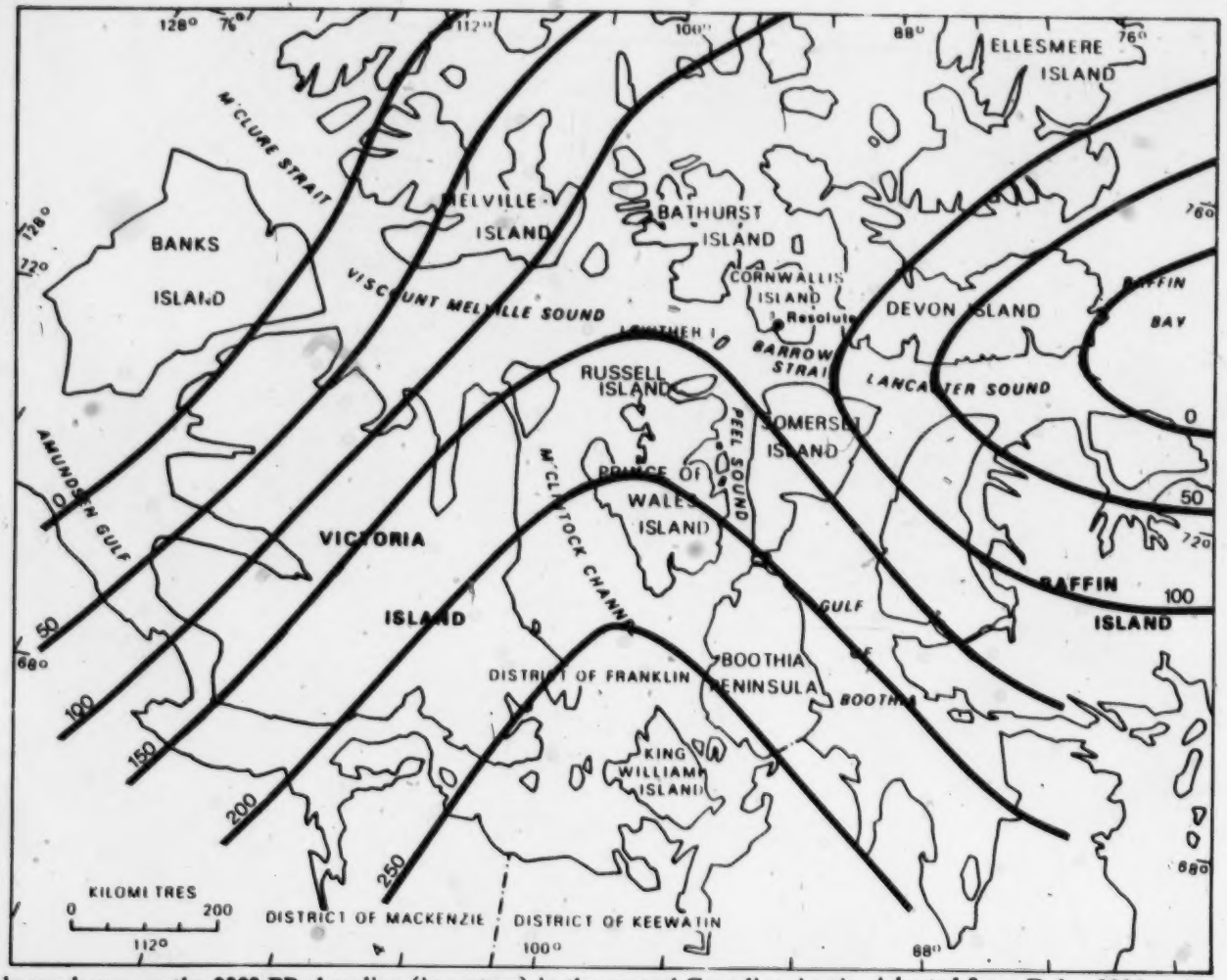


Figure 1.3 Isobases drawn on the 9300 BP shoreline (in metres) in the central Canadian Arctic. Adapted from Dyke, 1984, p.20.

M'Clintock Dome are discussed in the following section.

1.2.3 The M'Clintock Ice Divide Hypothesis

Dyke (in press,a) reconstructed the configuration and dynamics of the late Wisconsin ice cover in the central Arctic based on surficial mapping and the pattern of postglacial emergence. Dyke's reconstruction suggests that: at the glacial maximum, prior to 11,000 BP, the M'Clintock Ice Divide had a north-south orientation over M'Clintock Channel, between Prince of Wales and Victoria islands (Fig. 1.1 and 1.2). From this divide, M'Clintock ice flowed westward across Victoria Island to Admundsen Gulf, leaving highlands in the western part of the island as nunataks (Vincent,1982). Northward from the divide, the Viscount Melville Sound Ice Shelf extended across Viscount Melville Sound where it grounded on southern Melville Island in the northwest and terminated between Lowther and Griffith islands in the northeast. Eastward from the divide, ice crossed Prince of Wales Island and continued across Peel Sound to southern Somerset Island. South of this area, the ice shifted to a northeasterly direction over Boothia Peninsula. Dyke (in press,a) speculated that the eastern margin of the M'Clintock ice would have formed an ice shelf in the Gulf of Boothia which, in turn, contacted the western margin of the Foxe Dome (Fig. 1.4).

The eastward flow of M'Clintock ice extended onto western Somerset Island, coalescing in some areas with a radially flowing ice cap which was centred on the northeastern plateau of the island (Dyke, 1983; in press,a). Along the length of western Somerset Island, the margins of the M'Clintock ice and the local ice cap were separated by a range of nunataks now characterized by a more weathered terrain. The central part of the Somerset Island Ice Cap was cold-based and left very few erosional or depositional features. Nonetheless, the periphery of the ice cap (up to 50 percent of its area) was warm-based and produced both erosional and depositional features. The subsequent pattern of ice retreat is best demonstrated by the concentric pattern of ice marginal meltwater channels. The thicker, more erosive M'Clintock ice left widespread ice flow features in southern and western Somerset Island and northern Boothia

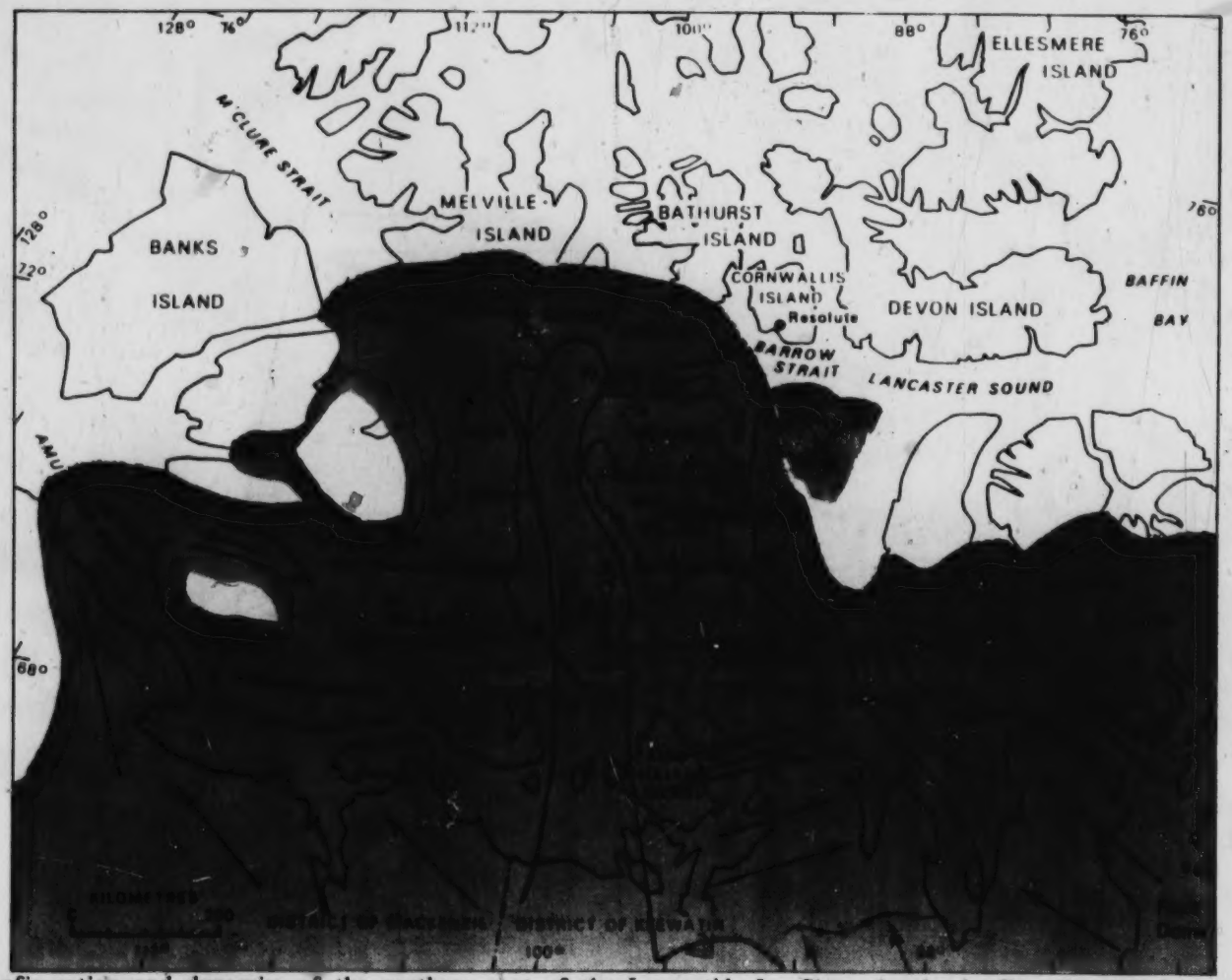


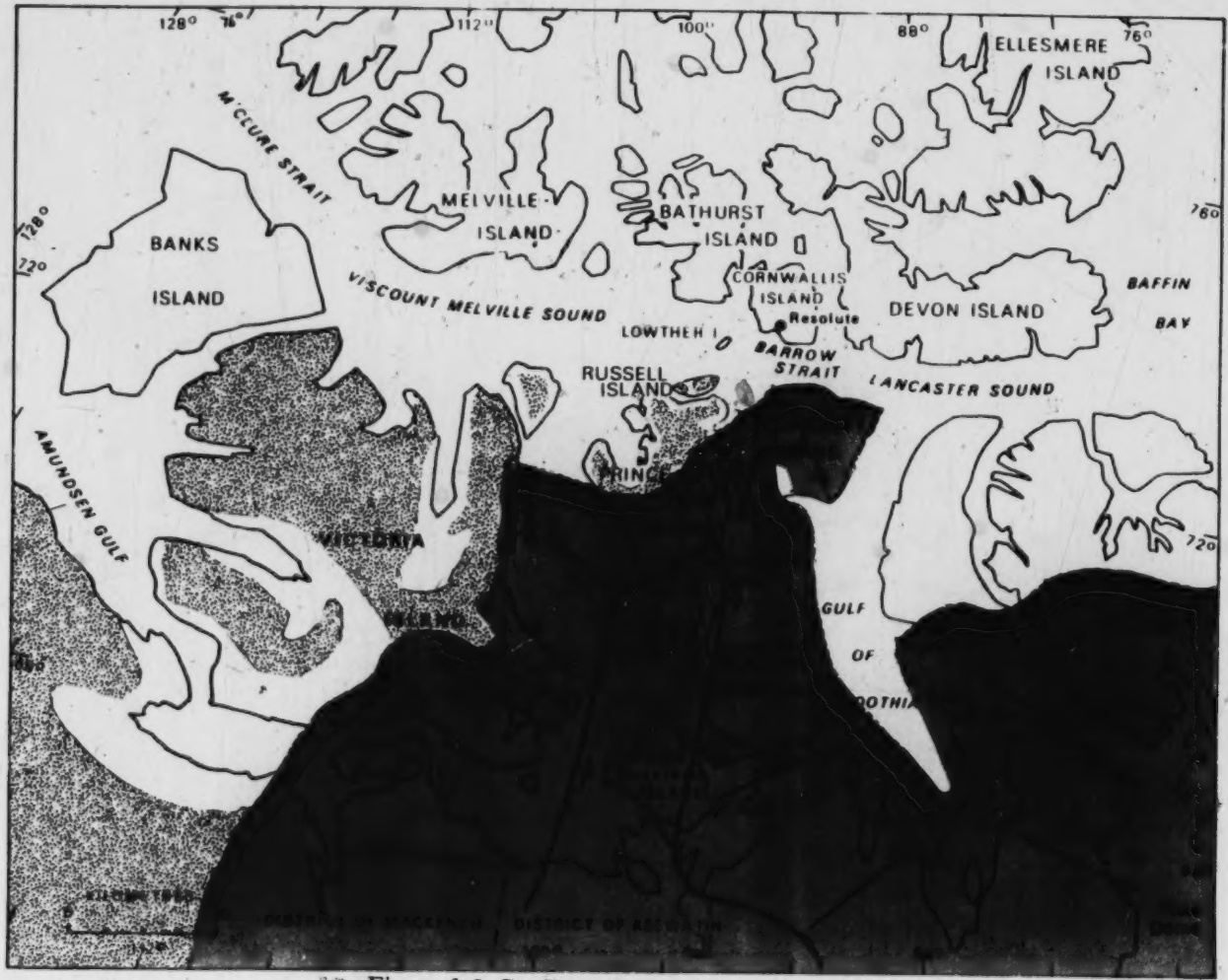
Figure 1.4 Configuration and dynamics of the northern part of the Laurentide Ice Sheet showing ice flow directions between 18,000 and 11,300 BP. Adapted from Dyke, 1984.

Peninsula. In addition, eastward dispersal trains of distinctive, carbonate-rich till outline two large, fast-flowing basal ice streams that crossed southern Somerset Island and Boothia Peninsula (Dyke, 1984).

Marine limit marks the uppermost extent of the postglacial sea and, for those sites inside the last ice limit, a radiocarbon date on it records the initial penetration of the sea, hence the time of deglaciation. Dyke (in press,a) has reconstructed the preliminary stages in the deglaciation of the M'Clintock Dome by mapping the available radiocarbon dates on marine limit inside its former margin. Most recently, dates from northern Prince of Wales Island indicate that deglaciation commenced there by 11,000 BP (Dyke,in press,b). The Viscount-Melville Ice Shelf to the north had disappeared, leaving the Winter Harbour Moraine on southern Melville Island (Fig. 1.5, Hodgson and Vincent, 1984). By 9600 BP, ice had withdrawn across northern Prince of Wales Island (Dyke, in press,a) and the western margin of M'Clintock ice had retreated to eastern Victoria Island, depositing the Nygard Moraines (Fig. 1.5). However, the easterly flow of M'Clintock ice was still relatively unchanged; the margin had retreated only slightly in the Gulf of Boothia (Fig. 1.5).

By 9250 BP, the M'Clintock Dome was much reduced, exposing central and northern Prince of Wales Island, southern Somerset Island and all but the southeast corner of Victoria Island (Fig. 1.6). The Somerset Island Ice Cap still covered much of the central part of the island. Between 9250 and 8800 BP, deglaciation became rapid on Boothia Peninsula (Fig.1.7) and the average rate of retreat was 200 m/year (Dyke, 1984). Dyke (1984) also noted that initial glacioisostatic emergence was as much as 30 m per century along eastern Boothia Peninsula. This rate of emergence is much higher than rates recorded elsewhere in the Arctic islands and it reflects rapid glacial unloading.

By 8800 BP, the main ice divide was located over the District of Keewatin and all of Prince of Wales Island, Somerset Island and Boothia Peninsula were ice-free (Dyke, in press,a; Fig. 1.7) Large areas of land had emerged from the sea (Fig. 1.7). As the remnant of the M'Clintock Dome, the Keewatin ice divide migrated southeastwards towards Hudson Bay where



Areas above sea level -

Figure 1.5 Configuration and dynamics of the northern part of the Laurentide Ice Sheet showing ice flow directions at 9600 BP.

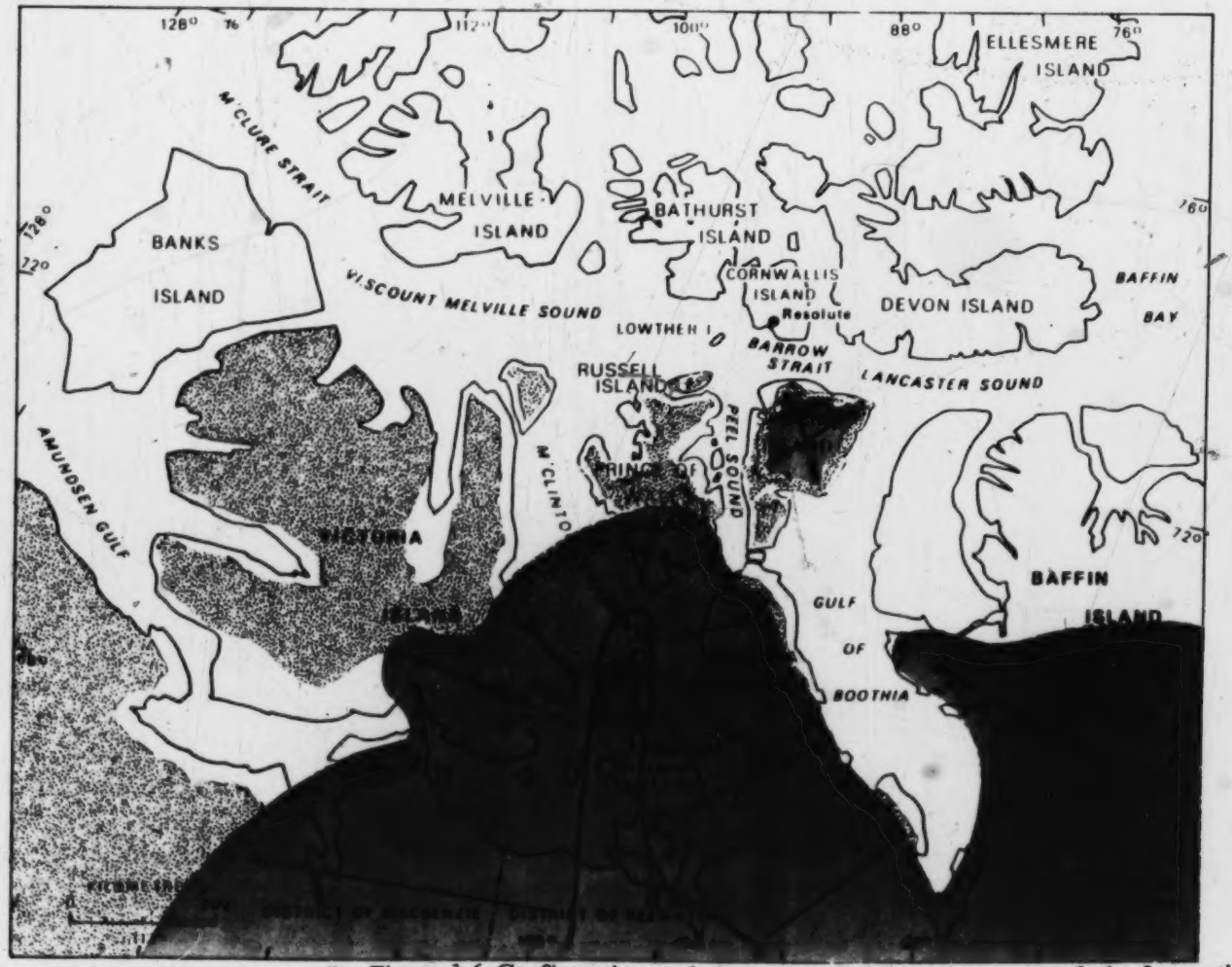
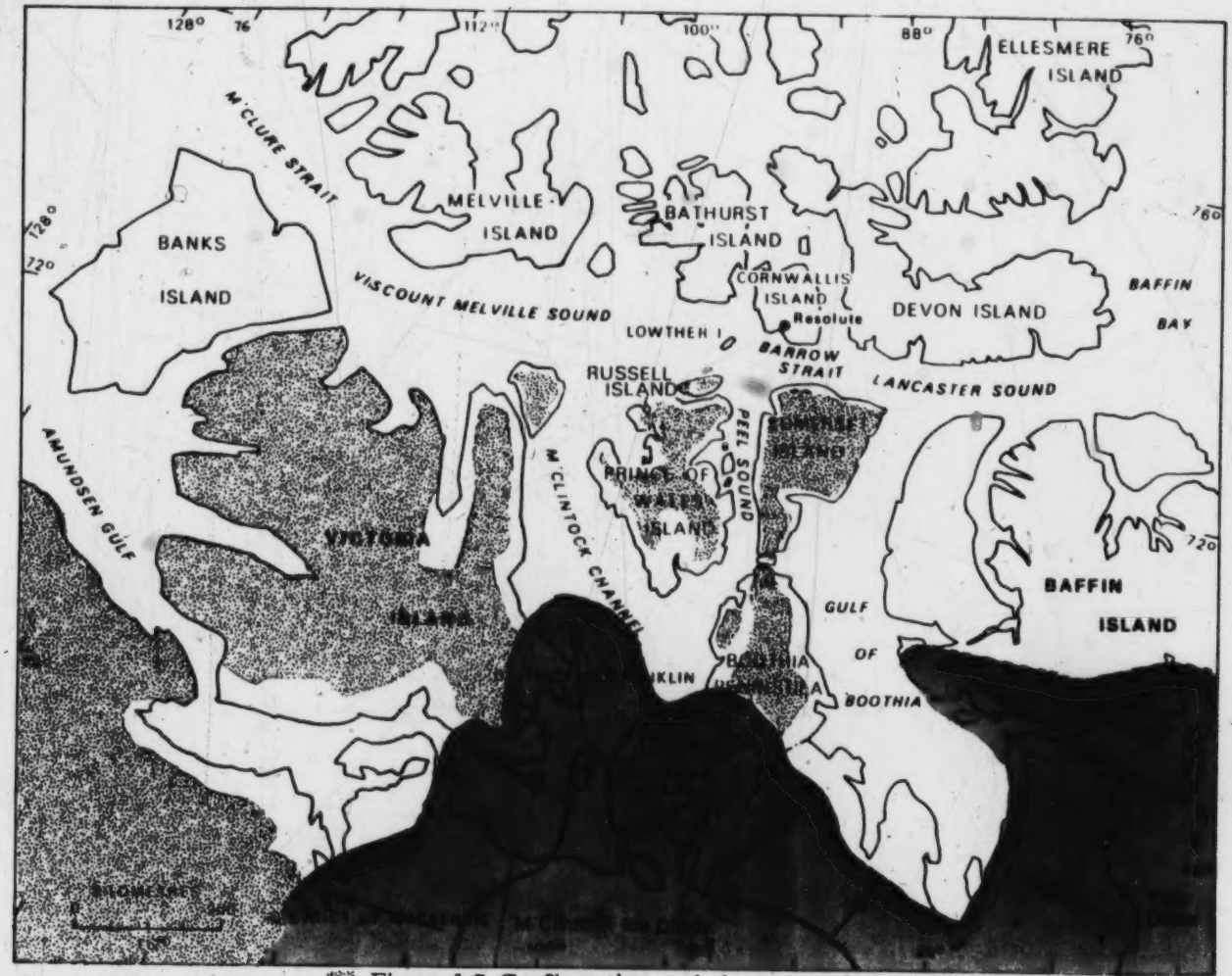


Figure 1.6 Configuration and dynamics of the northern part of the Laurentide Ice Sheet showing ice flow directions at 9250 BP.



Areas above sea level –

Figure 1.7 Configuration and dynamics of the northern part of the Laurentide Ice Sheet showing ice flow directions at 8800 BP.

it broke-up during the incursion of the Tyrrell Sea at 8000 BP (Andrews et al., 1983).

1.2.4 Conclusion

Knowledge of the late Quaternary history of the central Arctic has developed considerably during the last decade. This progress is based on detailed field mapping, particularly of till composition, and a much improved sea level history (Dyke, 1983, 1984). This has led to a greater understanding of the dynamics along the northern margin of the Laurentide Ice Sheet. The latest research indicates that ice dispersal during the last glaciation was quite different from what was originally presumed. A number of ice dispersal centres coalesced across northern Canada (Fig. 1.2) and these shifted considerably during deglaciation. Ice spreading from the M'Clintock Ice Divide covered most of the central Arctic and left much of the surficial materials and features found on this landscape today. Evidence of previous glaciations during the Quaternary Period is not well preserved in the region (Dyke, 1983).

1.3 Objectives of the Study

Despite these recent advancements, it should be noted that since Craig (1964) mapped several ice flow directions on Prince of Wales Island, the details of the glacial and sea level history of that area have remained unstudied. Because of this, the purpose of this study concerns Russell Island, located off the north coast of Prince of Wales Island. Previous research has not been conducted on Russell Island and therefore it provides a test of the regional ice dynamics and history hypothesized by Dyke (1984, in press, a,b). Because of the importance of this area in relation to the newly recognized M'Clintock Dome, the Geological Survey of Canada supported the fieldwork for this study during the summer of 1984. The objectives of this study include:

1) mapping the island's surficial deposits;

2) surveying the profile of its marine limit and lower relative sea levels;

3) collecting samples for C^{14} dating of the raised marine shorelines;

4) synthesizing objectives 1 through 3 in order to determine the island's late Quaternary history and comparing that with the previous and ongoing research.

2. STUDY AREA: LOCATION AND DESCRIPTION

2.1 Location

Russell Island (73°55'N, 98°30'W) is located 6 km north of Prince of Wales Island, across Baring Channel (Fig. 2.1). It comprises an area of approximately 950 km², extending about 58 km in length by 23 km in width. The place names on Russell Island, used in this study, are given on the 1:250,000 map sheets for Baring Channel and Lowther Island, 68D and E, NTS.

2.2 Physiography

Russell Island was described as a "mesa-like outlier" of the northern highland plateau of Prince of Wales Island (Roots, 1963, p.115). The eastern part of Russell Island is the highest, attaining elevations of just over 250 m asl (Fig. 2.2). At Cape Walker, on the east coast, the resistant bedrock upland forms a cliffed shoreline. The relatively uniform surface of the island dips to the west where elevations descend to 170 m asl. At the western end of the island the plateau is incised by a central lowland, in turn, occupied by a north-south oriented lake, 12 km long, which almost divides the island (Fig. 2.3). The lowland is associated with the strike of less resistant beds of argillaceous limestone and shale.

The physiography of Russell Island is a product of both lithology and periods of erosional planation. The main geological influence is the thick conglomerate and sandstone bedrock of the Peel Sound Formation which occurs exclusively in the eastern part of the island, providing the resistant structure for the mesa-like form of the highlands. In addition to this, an upland surface of erosional planation, the Barrow Surface, is found throughout the central Arctic and best exemplified by the plateau of northeast Somerset Island (Bird, 1959). The surface is traceable on both sides of Barrow Strait -Lancaster Sound (Fig. 2.1) and is therefore thought to have formed during late Cretaceous to early Tertiary time prior to the Eurekian Rifting Episode (Miocene-Pliocene age; Kerr, 1980). The planation of the Barrow Surface

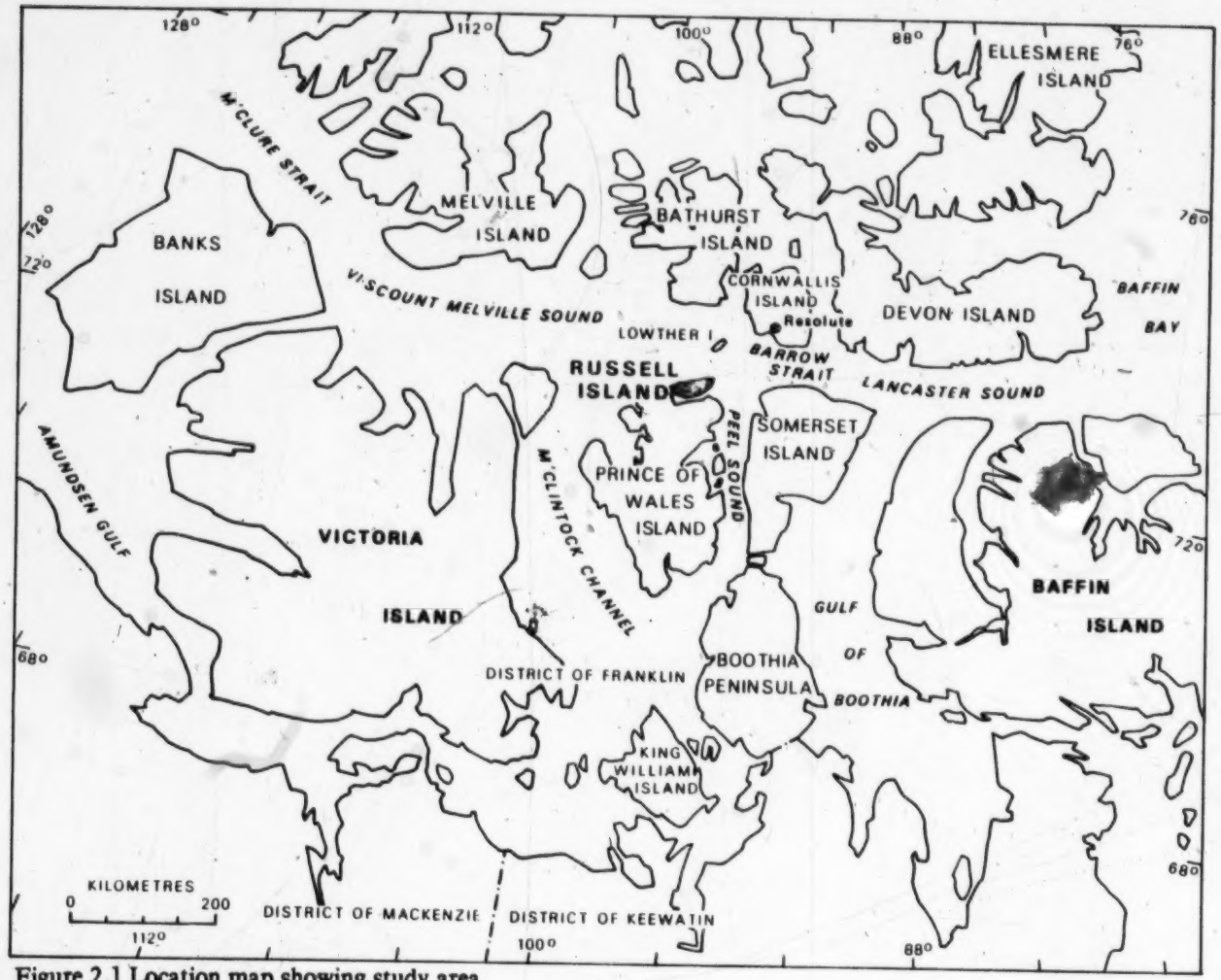


Figure 2.1 Location map showing study area

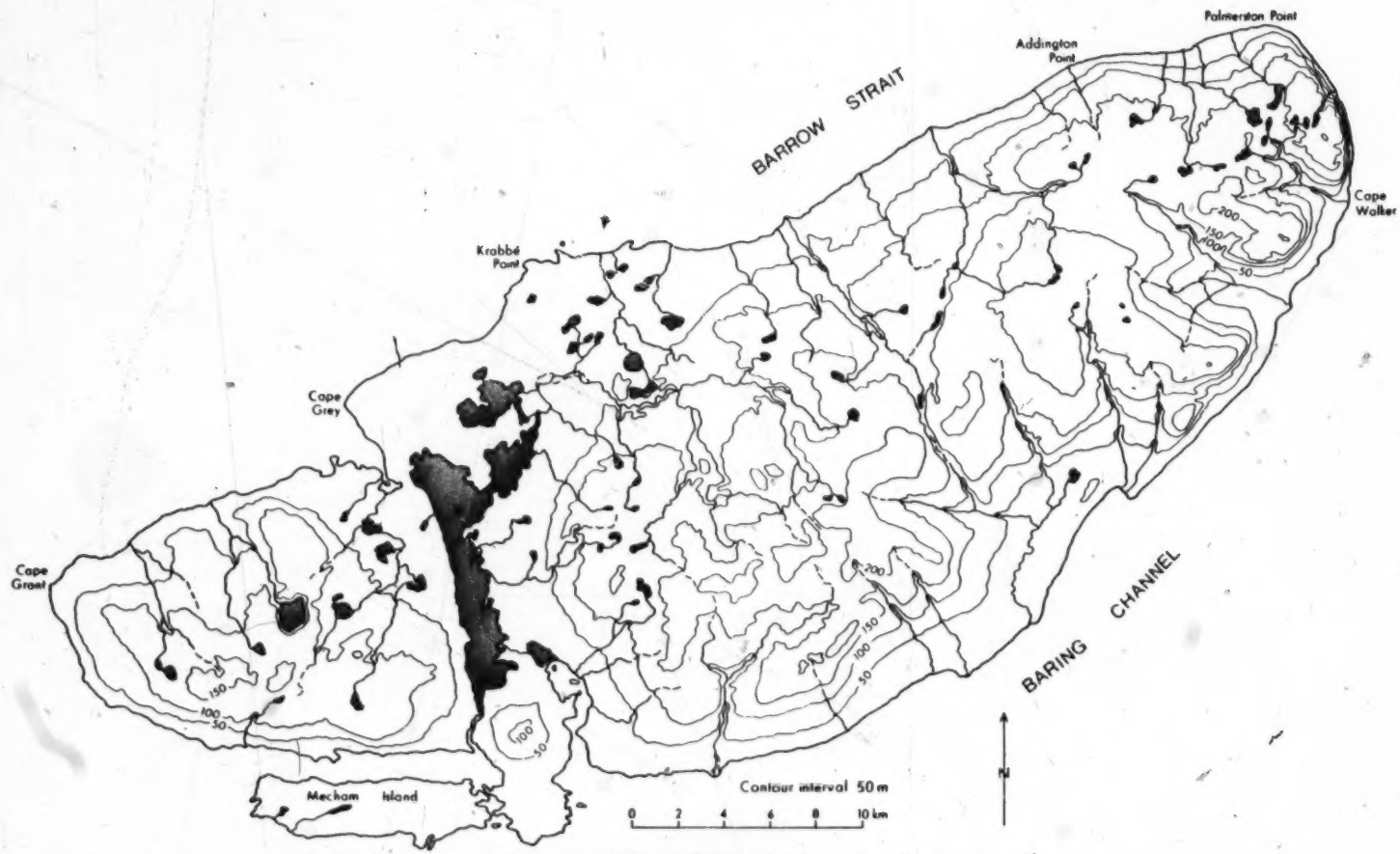


Figure 2.2 Topographic map of Russell Island (elevations in metres asl).

Figure 2.3 A view southward across the lowland of western Russell Island. Foreground: Till blanket and raised beaches with intermediate lakes and streams. Midground: Large lake (unnamed). Background: Baring Channel and Prince of Wales Island.

extends across Russell Island, creating the westward-dipping plateau now characterized by a mature drainage system (Bird, 1967) (Fig. 2.4).

2.3 Bedrock Geology

The sedimentary bedrock of Russell Island ranges in age from Silurian to Devonian (Blackadar and Christie, 1963). The beds are virtually undisturbed and therefore belong to the Arctic Platform structural province (Thorsteinsson et al., 1980). Two bedrock formations; Peel Sound and Drake Bay, outcrop on Russell Island (Fig. 2.5). The Peel Sound Formation (Silurian/Devonian) is divided into an upper and lower unit. The lower unit is approximately 200 m thick and consists of red and grey beds of siltstone, sandstone and conglomerate interbedded with marine carbonates. The upper unit is dominated by red-weathered, polymictic conglomerate over 300 m thick (Miall, 1970). The conglomerate clasts are dominantly carbonate and sandstone lithologies. The conglomerate facies of the Upper Peel Sound Formation wedges out westward into red weathered sandstone and red, yellowish, grey, and green-coloured carbonate facies (Mayr, 1978).

The Peel Sound Formation grades into the Drake Bay Formation (Silurian/Devonian) in the western part of the Russell Island. The Drake Bay Formation is approximately 1200 m thick and has its type section on Russell Island (Panarctic Russell E-82 well). The Drake Bay beds consist mostly of buff and mauve, weathered dolomite with some interbeds of dark grey siltstone and shale. Both the Peel Sound and Drake Bay Formations gradationally overlie the Read Bay Formation (Silurian). The Read Bay Formation, which does not outcrop on Russell Island but is exposed on northeastern Prince of Wales Island, consists of grey, argillaceous limestone (Mayr,1978)

Miall (1970) made a paleogeographical study of the Peel Sound conglomerates using sedimentological parameters such as clast size, lithologies, sphericity and imbrication. Eleven ancient alluvial fans (Peel Sound Bahada) were identified in the region, the largest of which deposited the subaerially weathered conglomerate and sandstone facies on Russell Island. The

Figure 2.4 Deeply dissected river valley cut into the Barrow Surface on the south-central plateau of Russell Island.

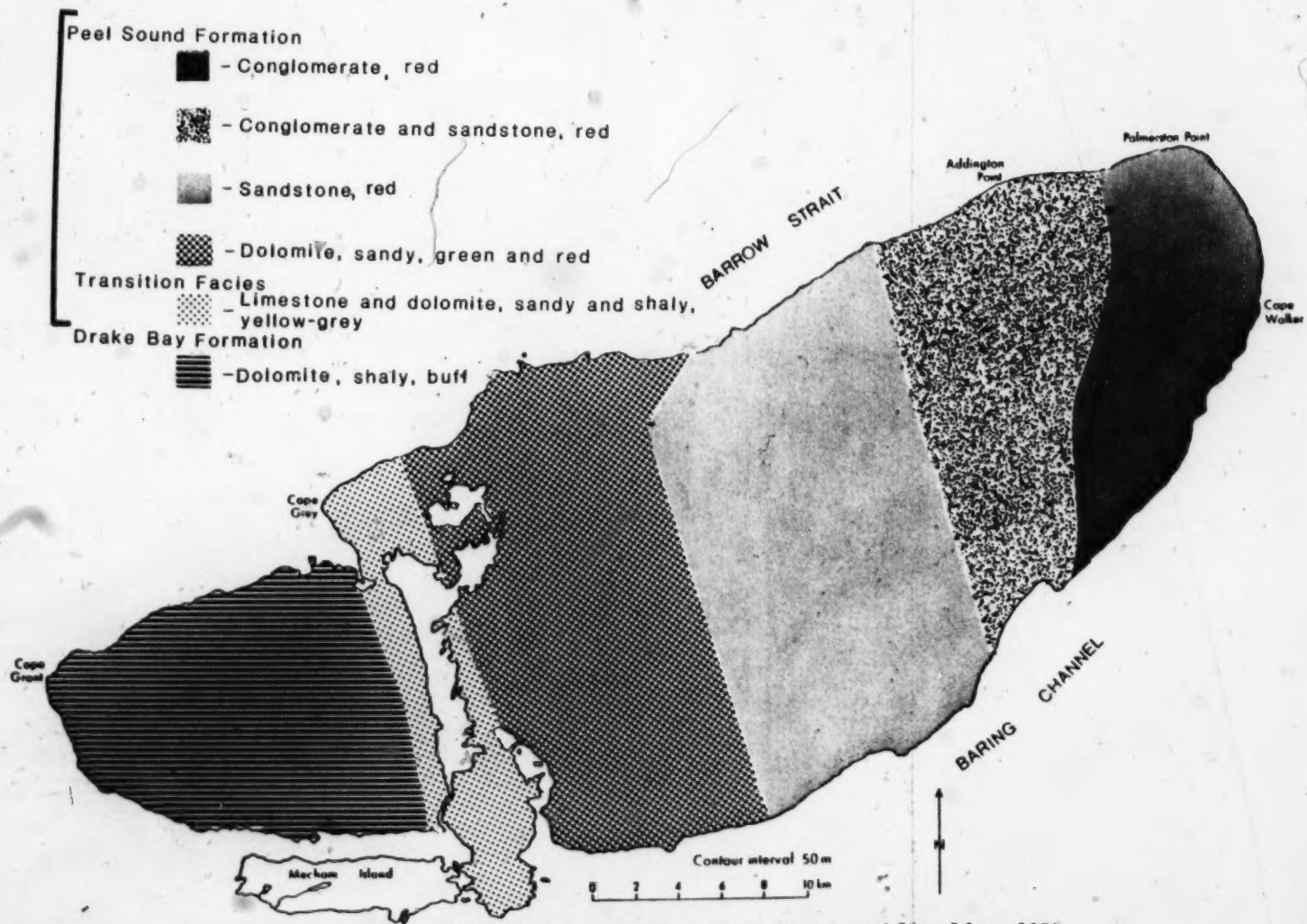


Figure 2.5 Surface bedrock of Russell Island. Adapted from Mayr, 1978.

alluvial fans were formed during the late Silurian and early Devonian Periods, prograding westward into the sea from the highlands of the Boothia Uplift. Erosion of the Boothia Uplift has left basement Proterozoic igneous and metamorphic rocks exposed through Boothia Peninsula, western Somerset Island and the eastern rim of Prince of Wales Island. Although these areas could be the source of the Precambrian erratics found on Russell Island, caution must be taken because the local conglomerates contain significant numbers of shield clasts (Miall,1970). Nonetheless, because the surface bedrock on Russell Island is comprised of distinct lithologies which systematically grade from conglomerate in the east to dolomite in the west, analyses of surface tills provides an ideal opportunity to determine the dispersal of these rocks by past glacial activity.

2.4 Climate

Russell Island has a high Arctic, maritime climate. The winters are characteristically long, cold and dry whereas the summers are brief, cool and damp. Resolute Bay, to the north of Barrow Strait, on Cornwallis Island, provides the closest climatic data (Table 2.1). There, the mean annual temperature is -16°C and the total annual precipitation is 137.3mm, most of which occurs during the months of July and August. The area could therefore be classified as semi-arid. Miller et al. (1975) estimated that the glaciation level in the area is ca. 500 m asl.

During the winter, the strong Icelandic Low pressure system in the direction of Baffin Island interacts with the Yukon High pressure system to cause persistent northwesterly winds through the central Arctic. Winter precipitation is associated with weak frontal activity (Barry, 1967; Bird, 1967) and its resulting snowfall is usually blown off the uplands, collecting in the valleys. By the middle of June, mean daily temperatures rise above freezing and surface thaw commences (Bird, 1967). On many stream banks, the collected snow is protected from direct insolation and therefore, it may form semi-permanent snow patches. On Russell Island, the nival flood was essentially completed before fieldwork began on July 13, 1984. The remaining streams were fed by melting ground ice, remnant snow patches and local summer precipitation.

TABLE 2.1 - CLIMATIC DATA FOR RESOLUTE, CORNWALLIS ISLAND

MEAN MONTHLY TEMPERATURES (C)

J	F	M	A	M	J	J	A	S	O	N	D	Mean Annual	Range
-33	-34	-31	-23	-11	0	4	3	-5	-15	-24	-29	-16	38

MEAN MONTHLY AND MEAN ANNUAL PRECIPITATION

	J	F	M	A	M	J	J	A	S	O	N	D	Mean Annual Total	
Rainfall (mm)	0.0	0.0	0.0	0.0	T	5.8	23.4	25.7	3.8	T	0.0	0.0	58.7	
Snowfall (cm)	2.8	3.3	3.3	5.8	8.9	6.6	3.0	4.8	14.2	15.5	5.6	4.8	78.6 / 137.3mm	(Divide by 10 for approx. water equivalent)

From: Atmospheric Environment Service (1975)

Typical summer circulation features a shallow cyclonic system over Hudson Strait with a series of irregular, synopic scale disturbances moving eastward in a frontal belt through the central Arctic Islands (Barry and Hare, 1974). Sub-synoptic scale disturbances are facilitated by the seasonal break-up of sea ice which initiates moist and unstable weather conditions. Consequently, onshore winds commonly cause low stratus clouds, local precipitation and fog during the summer and early fall. These conditions were prevalent throughout the 1984 field season on Russell Island (July 13 to August 26). The highest temperature recorded that summer was 12°C but most days reached only 5°C to 7°C. The mean daily temperature drops below freezing in the central Arctic in early September and the pattern of winter circulation usually begins abruptly by the end of that month (Thompson, 1965).

2.5 Vegetation and Soils

The vegetation and soils of Russell Island are only briefly discussed here. Russell Island was classed within the High Arctic ecological region by Zoltai and Woo (1976). The polar desert vegetation of this ecoregion is characterized by species-poor, relatively unproductive and structurally simple plant communities. The soils are predominantly regosolic turbic cryosols in which there is an absence of pedogenic development. The active layer depths are commonly less than 60 cm.

The carbonate-rich tills of the western part of Russell Island are fine-textured, nutrient-poor and have shallow active layers. Where this till occurs the vegetation is sporadic (5 to 10 percent cover) and usually consists of crustose lichens (on rocks) and tussocks of vascular plants such as purple saxifrage (Saxifrage oppositifolia), mountain avens (Dryas integrifolia) ,arctic poppy (Papaver radicatum) and locoweed (Oxytrophia arctica). The eastern part of Russell Island has the same plant species but generally tends to have more vegetative cover (10 to 30 percent) because of coarser substrates, more available nutrients and deeper active layers.

On a local scale, there are more specialized vegetation communities. In poorly drained areas, for example adjacent to lakes, vegetation can reach 100 percent cover with such plants as cotton grass (Eriophorum spp.) and sedges (Carex spp). On xeric sites such as raised beach ridges, scattered communities of reindeer moss (Cladonia spp.) and arctic willow (Salix arctica)- mountain avens (Dryas integrifolia) are prominent. Some of these local vegetation habitats are important food sources for the caribou.

3. METHODOLOGY

This study was designed to investigate late Quaternary glacial and marine events on Russell Island. This was done using two main methods. Firstly, the surficial materials and landforms were described and mapped across the island. Secondly, the pattern of postglacial emergence was determined by surveying marine limits and dating organic materials collected from raised marine sediments so that an emergence curve could be constructed. This chapter describes the procedures used during fieldwork and during subsequent laboratory analyses.

3.1 Field Mapping Procedures

The mapping of terrain on Russell Island followed procedures commonly used by the Geological Survey of Canada. Preliminary surficial mapping was done on aerial photographs before going to the field. All the photographs are at a scale of 1:63,000 and were taken in the summer of 1958. Using the aerial photographs, the surficial materials on Russell Island were tentatively identified and subdivided into eight genetic categories. Bedrock was differentiated mainly by structure and drainage. Till surfaces and thickness (blanket or veneer) were identified by surface features, tone and the degree to which underlying bedrock structure was obscurred. The tone is directly related to vegetative cover. Generally, till blankets are darker with more vegetation whereas till veneers are lighter in tone and poorly vegetated. Glaciofluvial, glaciomarine and active alluvial sediments were differentiated by morphology, tone and location.

In the field, ground traverses were made on Honda ATV's from four different base camps. Consequently, very little of Russell Island remained uninvestigated. Therefore, the aerial photograph interpretations were thoroughly ground-truthed and some initial, map unit boundaries were readjusted. Large geomorphic features such as eskers were mapped on the aerial photographs and their structural characteristics (such as pebble orientation) and lithologies were noted in the field. Smaller features (such as minor kame hummocks), that were not identified on the aerial photographs, were mapped, photographed and the size, shape,

orientation, internal structures and lithologies were recorded in field notes.

The mapping of glacial striae on bedrock was also an important objective of this study. Three main sets of striae were observed in different parts of Russell Island. Each set displayed cross-cutting ice directions, indicating changing flow patterns during deglaciation. Because a magnetic compass is unreliable at this latitude, striation orientations were taken by aligning their directions with landforms which were visible on the aerial photographs or maps. Ice flow directions indicated by the striae were then compared across the island.

Ninety-eight till samples were collected over all parts of Russell Island (Fig. 3.1). In each case, surface conditions such as drainage, periglacial processes, vegetation cover, stoniness and lithologies were described. Sample pits were dug to the frost table (not necessarily the permafrost table) and the depth, sample colour and texture were recorded. Cross-sectional exposures of surficial material were rare on Russell Island and only two reliable till fabrics were taken from eroded stream banks.

3.2 Dating Former Sea Levels

Most coastal areas in the central Arctic were modified by the postglacial marine transgression. On Russell Island, at least 50 percent of the surface was covered by the postglacial sea, leaving extensive raised beaches and isolated deposits of glaciomarine silt. Most of the 1984 field season on Russell Island was spent searching the surface of the raised marine sediments for datable, in-situ organic material such as driftwood, marine mammal bones and shells. Over 50 organic samples were collected, 16 of which were radiocarbon dated at laboratories in Saskatoon and Ottawa (see Fig. 3.1).

The elevations were surveyed for each sample using either a stadia rod and quick-set level or an aneroid altimeter. The rod and level method is more accurate and was used as often as time permitted. The altimeter was employed on long traverses and the results were corrected for changes in temperature and pressure. The error obtained from altimetered elevations is considered to be +/- 2 m at ca. 100 m asl and less for lower elevations.

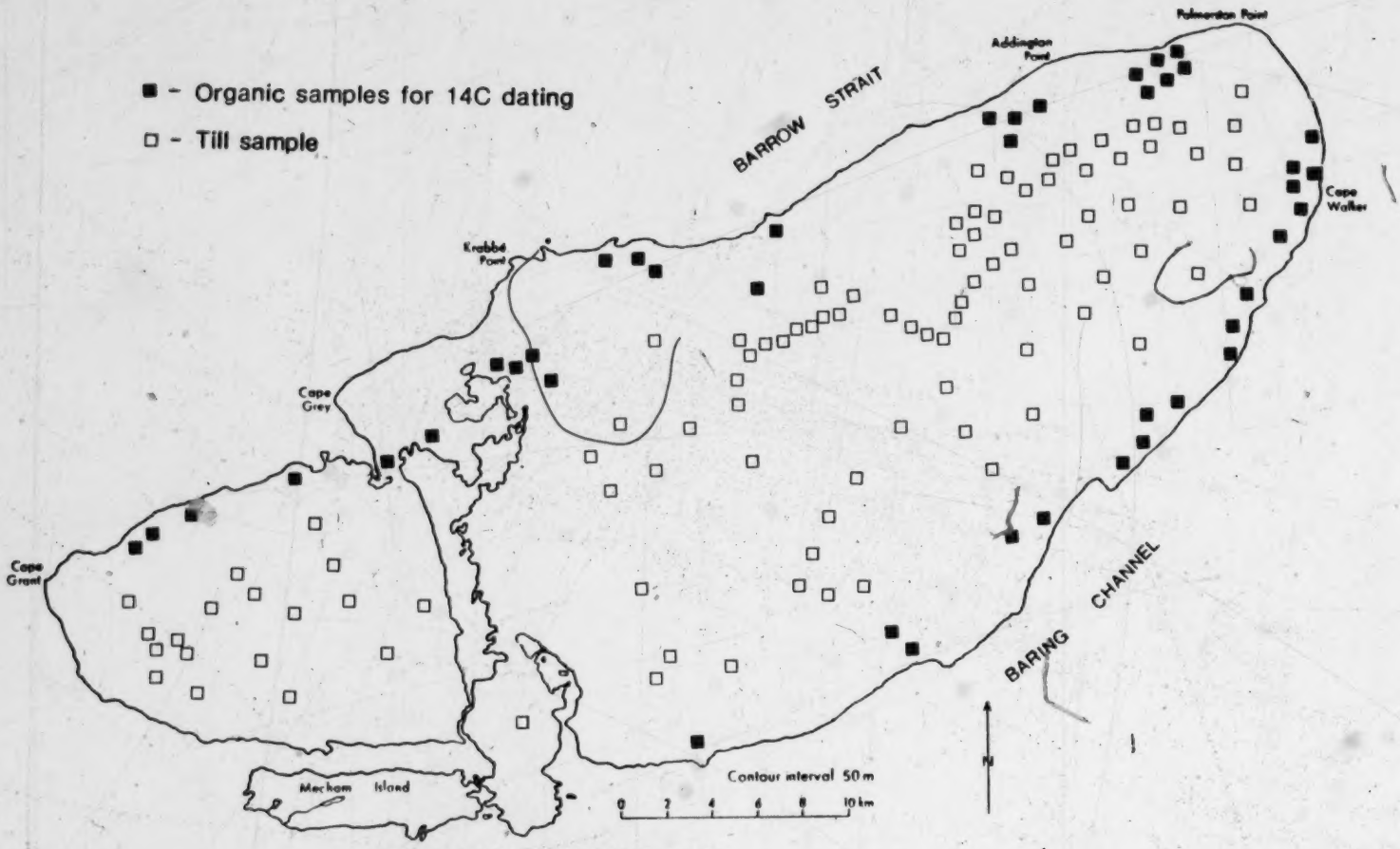


Figure 3.1 Sample location map.

The uppermost shorelines on Russell Island were found to be lower than expected based on the projection of well controlled isobases from surrounding islands (see Fig. 1.3). Consequently, they were carefully searched for organic material and surveyed at several points to reveal any tilt. Former shorelines are discussed in Chapter Five.

3.3 Laboratory Analyses

The till samples collected across Russell Island were analysed for two reasons: 1) To identify the range of till compositions; 2) To map differences in till characteristics which could be used to identify glacial flow patterns and distance of transport. The tills were analyzed for: colour, clast lithologies, particle size distribution and calcite/dolomite content. Each sample was also analyzed for trace elements by the Geological Survey of Canada. These are standard analyses used to investigate till provenances and patterns of glacial dispersal. Results of these analyses are mapped and discussed in Chapter Four.

3.3.1 Dry Munsell Colour

Each till sample was oven dried and its colour was classified using a Munsell Colour Chart.

3.3.2 Clast Lithologies

The >2 mm size fraction of each till sample was analyzed for lithologic composition by employing a percentage by weight method used at the Geological Survey of Canada. Firstly, the total >2 mm fraction was weighed. All the grit to pebble-sized particles were then identified as specifically as possible. Each lithologic group was then weighed separately and the percentage of the total sample was calculated by dividing the group weight (x100) by the total weight of the fraction.

The particles of the >2 mm fraction within each sample were also classified by shape and degree of faceting. The particle shapes primarily reflect the distance and mode of glacial

transport. The shapes were subdivided according to studies by Wentworth (1933), Krumbein (1941) and Holmes (1960) into three classes: high, moderate and low modification.

3.3.3 Particle Size Distribution

The particle size analysis followed the method of Bouyoucos (1962) in the Canadian Soil Science Manual (McKeague, 1978). A standard 40 grams of the <2 mm fraction was analyzed for each sample. Each sample was also pretreated with sodium hexametaphosphate to deflocculate the clays and disperse the suspension. A bouyoucos scale hydrometer, ASTM no. 152H was used to determine density and 8 readings were taken over 18 hours. Consequently, a well controlled summation curve was plotted for each sample and the percentages of clay, silt and sand were calculated directly from the intercepts.

3.3.4 Calcite/Dolomite Content

Calcite and dolomite contents were determined for each till sample using a quantitative manometric method developed by Skinner et al. (1959). Between 0.5 and 3.0 g of 200 mesh grade sample were analyzed. The sample size was determined for each till by a simple test of the degree of effervescence upon application of 6N hydrochloric acid. In the main analysis, the amount of CO^2 produced was measured by 15 burette readings taken in increasingly greater intervals of time. The dolomite component of the sample often took up to 60 minutes to completely react. The percentages of calcite and dolomite were calculated by plotting the results as a curve and using intercept values in an equation from Skinner et al. (1959). The system was periodically calibrated using pure calcite and any change in barometric pressure was recorded and a correction was applied to the results.

3.3.5 Trace Elements

The clay fraction of the till samples was analyzed for uranium using a fluorimetric technique and for base metals using the atomic absorption method at a commercial laboratory.

4. DESCRIPTION OF SURFICIAL MATERIALS AND GEOMORPHOLOGY

This chapter describes the surficial materials and landforms found on Russell Island and refers to a fold-out map inside the back cover (Fig. 4.1). Reconstructions of ice flow patterns and deglacial stages are briefly discussed using evidence from bedrock striae, till analyses and landforms. The divisions of surficial materials and associated landforms are described in order of relative age.

4.1 Bedrock

Outcrops of bedrock are common on Russell Island, comprising about 25 percent of the land surface. In the uplands, east of Addington Point (Fig. 4.1), most of the land surface consists of unweathered conglomerate and sandstone in places mantled by a till veneer or locally derived perched boulders. The bedrock bears evidence of strong glacial erosion; most exposures are well polished and faceted (Fig. 4.2). The resistant nature of this clastic bedrock has preserved ice flow features such as roches moutonnées, striae, grooves and miniature crag-and-tail, dominantly oriented in a northwest direction.

The glacially scoured bedrock of the eastern uplands exhibits a deranged drainage pattern. Faults and other bedrock structures in the conglomerate were exploited by glacial erosion creating numerous depressions which are now occupied by small lakes. At the east coast of Russell Island, the conglomerate bedrock forms steep cliffs which drop 200 m to thin beaches along the Peel Sound coast. Gullies etched along faults dissect some of the cliff faces, resulting in rockfalls and the development of large, unstable talus slopes at the base of the cliffs (Fig.4.3).

In contrast to the eastern surface, there is little exposure of bedrock in the central and western uplands of Russell Island (Fig. 4.4). The carbonate bedrock is less resistant to erosion and visible only as till-mantled knolls, low cuestas, small blockfields or in stream cuts. Generally, the rock surfaces are sufficiently frost shattered that glacial features are poorly preserved. Some bedrock striae were found by removing the protective till veneer. It was also

Figure 4.2 Glacially-scoured conglomerate with perched boulders on the eastern uplands of Russell Island. View is to the north, looking down an upland lake.

Figure 4.3 The east coast of Russell Island: 200m cliffs formed from the upper Peel Sound Formation conglomerate with screes formed from frost shattered bedrock.

Figure 4.4 Foreground: Till veneer on bedrock knoll on the central uplands of Russell Island.

observed that several of the larger bedrock knolls were roughly drumlinized by glacial flow towards the northwest.

Different carbonate rocks display different weathering characteristics. The argillaceous limestone in the central part of the island is thinly bedded and highly susceptible to frost action. The bedrock surface has shattered into thin plates which have been sorted into patterned ground by periglacial processes (Fig. 4.5). 1 The depth of in-situ frost shatter was found to be less than 30 cm. The more pure limestone and fine-grained sandy carbonates tend to fracture into larger, flat, angular plates which form felsenmeer. The dolomite in the west end of the island is more massive and tends to shatter into a felsenmeer characterized by angular blocks.

4.1.1 Striae

Sets of cross-cutting striae were found at three sites (Fig. 4.6). The oldest striae recorded at Site A are weakly inscribed but indicate ice movement toward 65°azimuth (ENE). The next older striae are superimposed on the first and indicate ice flow towards 290°(WNW). This ice flow was very erosive; polishing the outcrops and forming large grooves and roches moutonnées. Site A also records a later shift of ice flow toward 300° (WNW, Fig. 4.7). The oldest striae are best exhibited on the lee side of outcrops where they were not eroded by later flows.

Two striae directions were recorded on grey limestone at Site B. The earliest striae are indistinct and oriented at 325°(NNW). The second set of striae are strongly etched and oriented at 315°(NW). At Site C, an early indistinct ice movement was recorded on dolomite at 80°(E). A second set of striae cross-cut the early flow at 320°(NW), and a third ice flow direction was marked by deeper, stronger striae oriented at 300°(WNW).

These changing orientations of striae on the bedrock of Russell Island indicate that there was an early eastward flow followed by north to northwest flows. Therefore, ice from the M'Clintock Ice Divide presumably originated first from the west and later from the south and southeast with respect to Russell Island. This sequence resembles the reconstruction of the

Figure 4.5 Frost shattered, sorted, soft carbonate bedrock chips about 6 cm across on the western uplands.

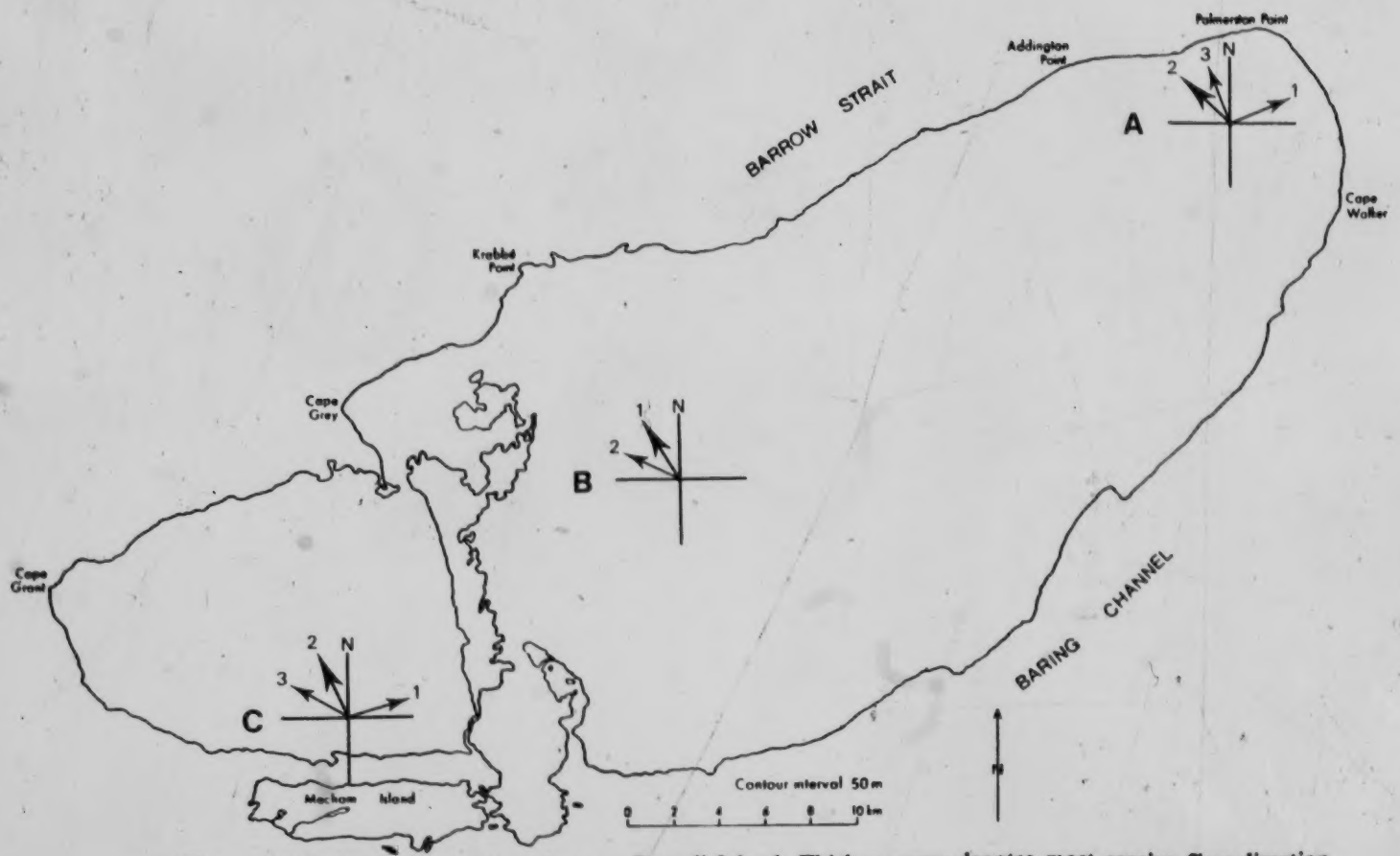


Figure 4.6 Bedrock striae orientations on Russell Island. Thicker arrow denotes most erosive flow direction.

Figure 4.7 Striae near Site A, eastern Russell Island, on the surface of conglomerate. The pencils mark striae orientations which record two directions of flow (bottom to top). Northwest striae (bottom pencil) are cross-cut by a more northerly flow.

northwestern Laurentide Ice Sheet presented by Dyke (in press,a) using data from other areas in the central Arctic (see Figures 1.4 to 1.7). The deglacial flow towards the northwest was very erosive and in most places it obliterated the record of the earlier eastward flow across Russell Island and parts of northern Prince of Wales (Dyke, pers. comm., 1984). A reconstruction of Late Wisconsinan deglacial events on Russell Island is presented in Chapter Six.

4.2 Till

Till is the most widespread surficial material on Russell Island and covers about 53 percent of its surface. The till is differentiated by thickness into two units: blankets and veneers (Fig. 4.1). Till blankets are more than 2 m thick and obscure the underlying bedrock whereas till veneers are less than 2 m thick and mimic the bedrock surface. The till blanket has subdued, rolling hills and is most extensive in the north-central and western parts of Russell Island. The till veneer is generally flatter and more stony than the till blankets. Till veneer is most common in the eastern half of Russell Island.

Till is solely a glacial sediment and its composition is a product of four main factors: 1) the type and properties of bedrock and reworked sediments over which the ice advanced; 2) size of source area and distance from source; 3) the processes of debris transportation; and 4) the mode of deposition and possible post-depositional alteration. These variables are considered during the interpretation of till analyses in this section.

4.2.1 Colour

In glacial studies, the determination of colour is a traditional technique used to describe and correlate tills (Goldthwait, 1971; Vincent, 1982). The colour of unweathered till is a function of the mineral composition of the matrix and therefore, reflects the source. The colours of the Russell Island tills clearly relate to mineral components derived from bedrock types on the island.

Figure 4.8 summarizes the results of till colour determinations on Russell Island. The island is divided into broad zones which represent till provenances based on colour. On southeastern Russell Island, the till veneers overlying the red conglomerate and sandstone range from brown, light reddish -brown and reddish-brown to red and yellowish-red. The central areas of the island, underlain by reddish sandstone and sandy carbonates are dominated by brown coloured tills, including all the morainal ridges along the north coast. Overlying the red, yellowish, mauve, grey and buff weathered carbonates on the western part of the island, there are light brownish grey, light grey, pale brown and light reddish brown tills. Generally, the tills exhibit grey tones in the west, brown in the central parts and red in the east (Fig. 4.8).

Although the till colours are generally similar to that of the underlying bedrock, some interesting anomalies exist. Most of the eastern and central till veneers overlying the red sandstone have a reddish colour whereas most of the till blankets overlying the red sandstone are brown. An especially abrupt boundary is located between the blankets and veneers in the uplands of northeastern Russell Island. In the west, the till veneers are pale brown and light grey whereas the till blankets are everywhere light brownish grey and light reddish brown. These colour contrasts suggest genetic differences; that they were incorporated, transported and/or deposited by different means. Generally, the till veneer colours are directly related to the underlying bedrock whereas those of the till blankets indicate longer transport. This conclusion is also supported by the results from other analyses and these are discussed in the landform section.

4.2.2 Clast Lithologies

An analysis of the clast lithologies within a till is commonly used to determine the source of the till and direction of glacial flow. For example, differentiation is made between Cordilleran vs. Laurentide tills in Alberta using crystalline erratics from the Canadian Shield (Stalker, 1963). In southern Ontario, Dreimanis and Vagners (1969) found that 70 to 90 percent of the clasts within lodgement tills were of local origin. However, rarely was >50

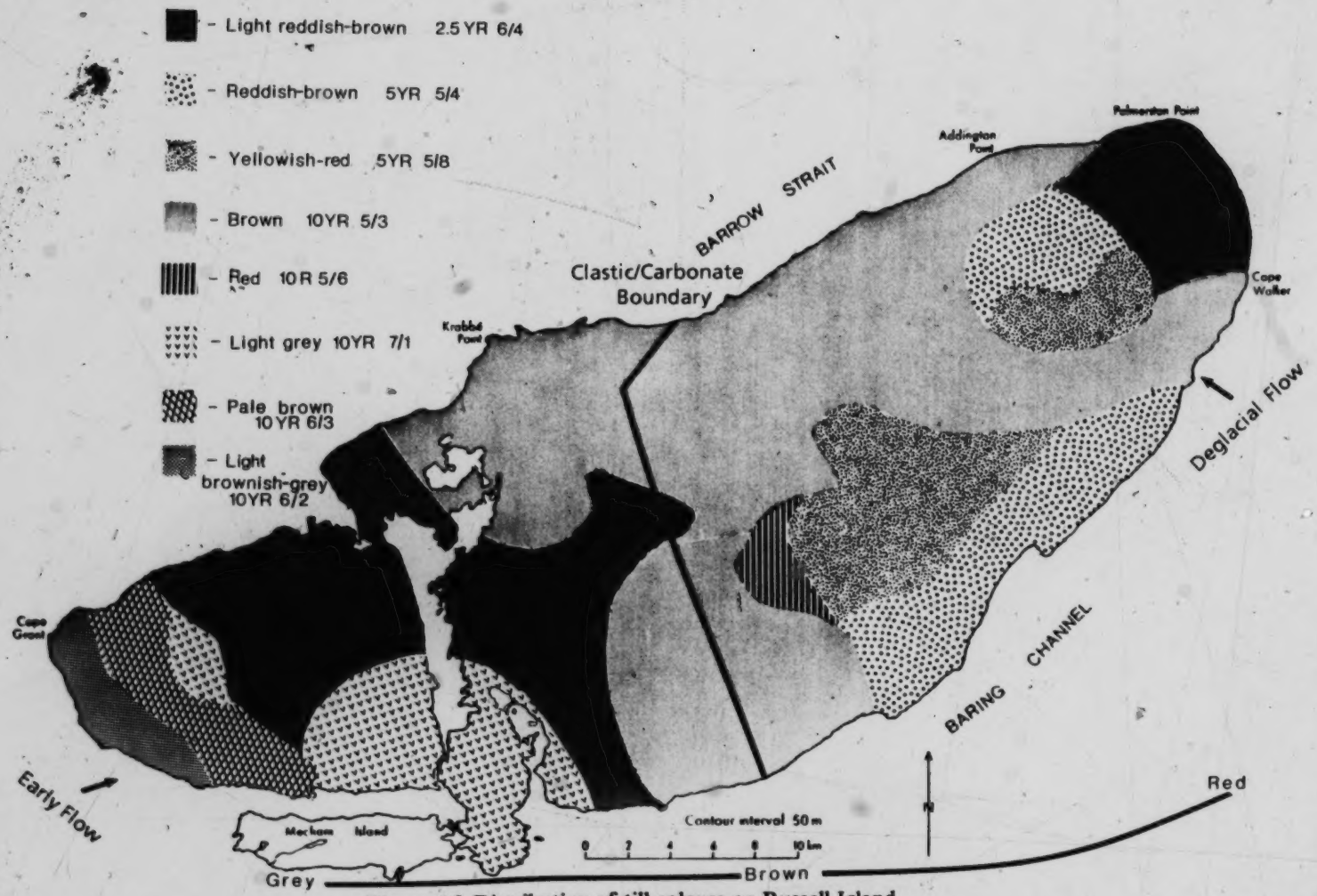


Figure 4.8 Distribution of till colours on Russell Island.

percent of the matrix composed of material from the local bedrock. Therefore, they concluded that the till matrix or mineral fraction retained characteristics from the more distal sources whereas the clasts were dominantly local. Linden (1975) made similar conclusions in southern Sweden, noting that clast lithologies varied greatly within 5 km due to changing bedrock whereas the mineralogy of the fine sand to silt grades remained more uniform.

Figures 4.9 and 4.10 illustrate the respective distribution of clastic and carbonate particles of >2 mm in size within the Russell Island till samples. In Figure 4.9, the clastic content reaches 100 percent in a number of till samples through the central and north-central areas of the island. The clastic content then drops steadily towards the southeast to less than 60 percent over the conglomerate bedrock. Westward, the percentage of clastic rocks drops very rapidly to 0 adjacent to the clastic/carbonate lithologic boundary. One plume, containing 60 percent clastics, extends several kilometres west of the boundary. No clastic particles were found in the tills of western Russell Island.

The carbonate clast content reaches 100 percent thoughout the western half of Russell Island and this extends just east of the clastic/carbonate boundary in the central uplands (Fig. 4.10). A tongue of only 20 to 40 percent carbonate clasts, associated with the higher clastic component, crosses west of the boundary and dominates the pattern in the south-central part of the island. The content of carbonate clasts drops rapidly to the east, falling to less than 20 percent over the sandstone bedrock in mid-eastern Russell Island. Nonetheless, many of the till blanket samples across northeastern Russell Island still contain over 20 percent carbonate clasts far to the east of the carbonate boundary. In some areas the carbonate clasts rise to almost 60 percent in the till veneers over conglomerate bedrock in the eastern uplands.

The clast distributions featured in Figures 4.9 and 4.10 are the product of two separate sources of carbonate. First, the early eastward glacial flow carried carbonate rocks from western Russell Island across the clastic bedrock. These clasts are moderately to well-faceted exhibiting flattened shapes. For example, scattered clasts of the conspicuous mauve weathered dolomite from the west coast of Russell Island were observed over the surfaces of the till

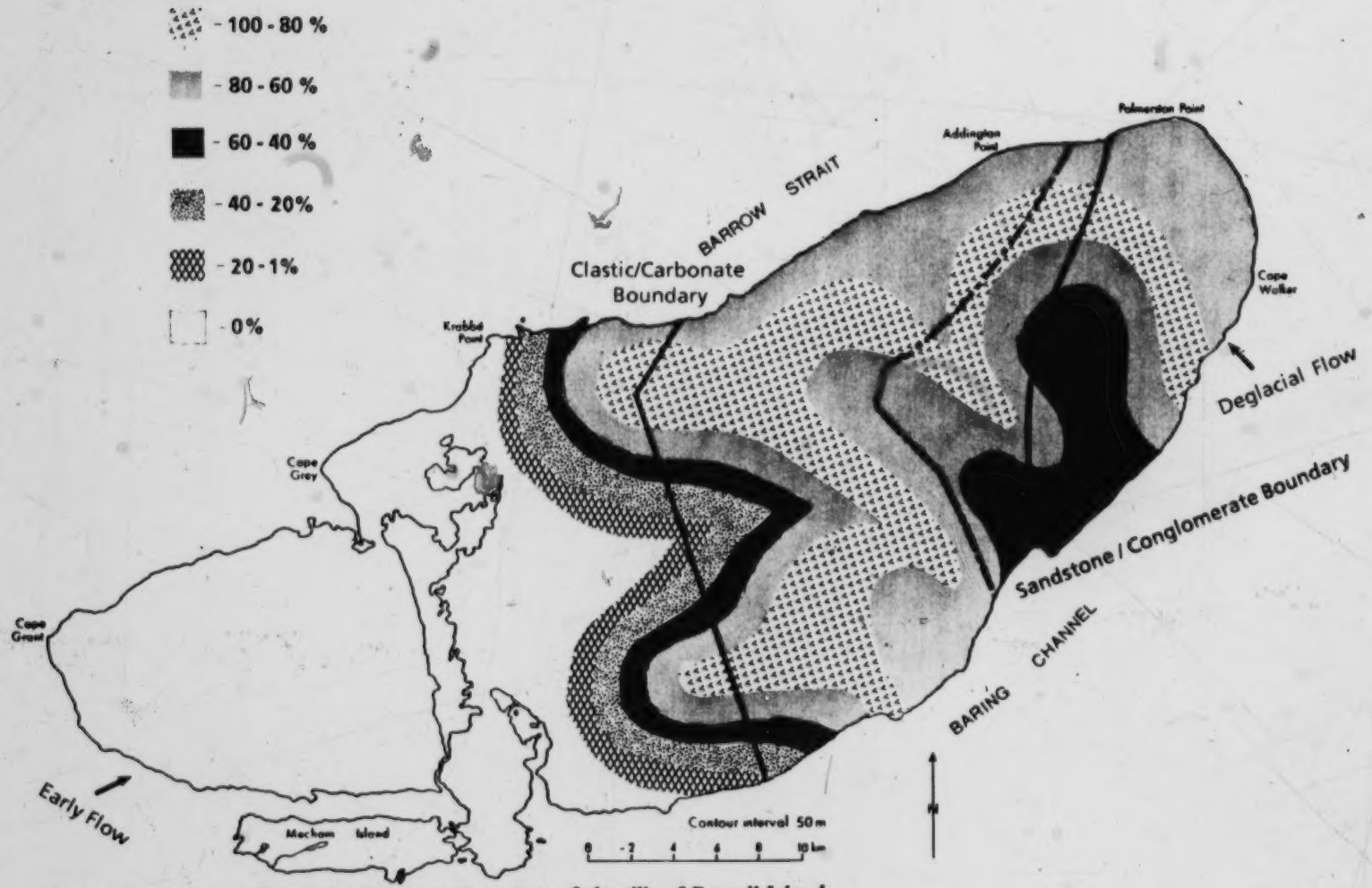


Figure 4.9 Clastic clast content of the tills of Russell Island.

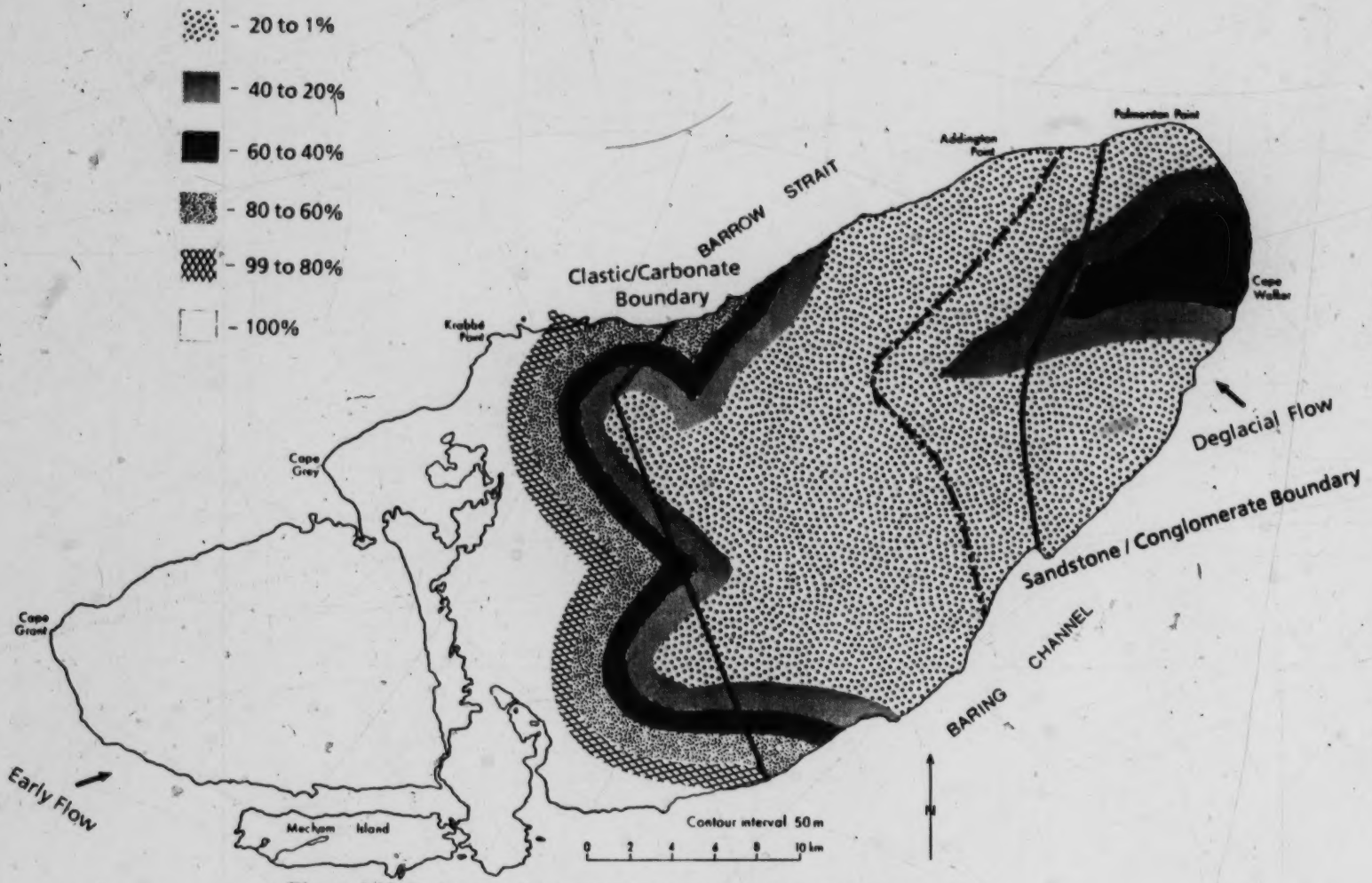


Figure 4.10 Carbonate clast content of the tills of Russell Island.

blankets on the northeast coast. Second, the northwesterly, deglacial flow eroded carbonate clasts from the Peel Sound Formation conglomerate and deposited them on the sandstone lithofacies. The conglomerate-derived carbonate clasts are identified by their poor faceting and roundness. The dashed line, on the map, through eastern Russell Island, approximates the limit of the conglomerate-derived clasts in the tills (Figures 4.9 and 4.10) which were transported less than 6 km by the northwest deglacial flow. East of this line, the western carbonate clasts are secondary to those derived from the conglomerate, generally constituting less than 30 percent of the carbonate total.

The percentages of crystalline erratics within the Russell Island till samples are low and variable. Twenty-nine percent of the total number of till samples record at least 1 percent crystalline clasts. The greatest numbers are found in the eastern half of the island. Only one sample reaches 1 percent crystalline clasts in the western half of the island. Throughout eastern Russell Island, 19 of 28 samples contain 2 percent or less crystalline erratics. The highest number of crystalline clasts is 7 percent found adjacent to the conglomerate/sandstone boundary.

The crystalline erratic clasts within Russell Island tills were derived from two sources. One source was the crystalline outcrops along eastern Prince of Wales and western Somerset islands or more distant parts of the Canadian Shield transported by successive Quaternary glaciations. The other source of crystalline clasts was the Peel Sound conglomerate. Distinguishing between clasts from these two sources is impossible because both ultimately have the same Shield source and both can be similarly sub-rounded and moderately to well-faceted. However, most of the crystalline clasts found within the conglomerate provenance are very well rounded which indicates alluvial transport in the ancient Peel Sound Bahada and therefore they are principally exhumed, fluvial erratics and not glacial ones.

More than half of the till samples containing crystalline erratics are west of the conglomerate provenance boundary. Of these, only one sample contains more than 3 percent crystalline clasts. Many of these clasts are well-faceted, suggesting that they could have been

derived by glacial erosion from areas outside of the conglomerates of Russell Island.

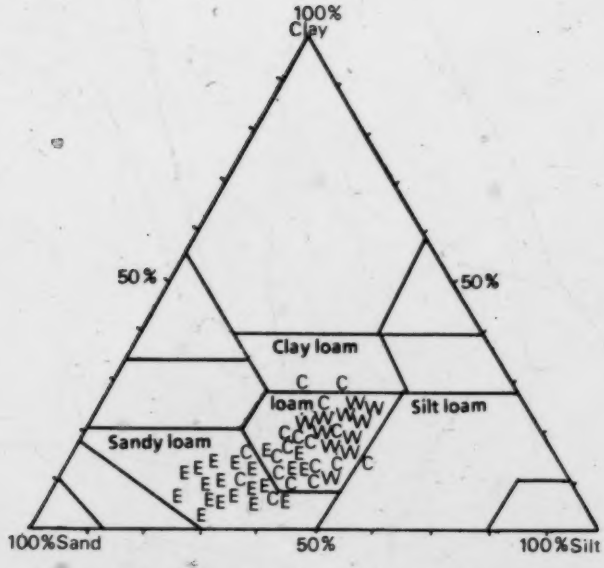
4.2.3 Texture

Till is generally regarded as an unsorted mixture of material with particles of all sizes. However, glacial processes tend to impose limits on the characteristics of till. Dreimanis and Vagners (1971) found that many tills exhibit a bimodal distribution of particle sizes. One mode is in the till matrix, consisting of mineral fragments and the other is in the clast size. If the parent bedrock consists of a variety of minerals, the till matrix is polymodal. The greater the distance of transport, the more dominant are the minerals' terminal grades resulting in fine till textures. Dreimanis and Vagners (1971) considered this to be a "mature" till.

Certain characteristics of past glacial events can be determined by quantifying various aspects of till composition. For example, till texture has been used to reconstruct depositional environments and assist in distinguishing between tills from different sources (Shepps, 1953; Drake, 1971; Fenton and Dreimanis, 1976; Shetsin, 1984). In this study, surface till samples were analyzed for texture mainly to reconstruct the direction and characteristics of the most recent glacial flows over the island.

More than ninety till textures were determined on samples collected on Russell Island and all of these are relatively similar despite the different bedrock types. Both till veneers and blankets in the eastern part of the island are sandy loams whereas most tills in the central and western parts are loams. Figures 4.11 and 4.12 indicate that from east to west, there is a systematic decrease in the sand content; a persistence of silt-sized particles; and a rise in clay content. This general trend is due directly to the change of bedrock source for the till. The coarser eastern tills are derived from the conglomerate and sandstone bedrock whereas the finer tills of the central and western part of the island are derived from the carbonate bedrock.

Figure 4.11 shows that till blanket textures on Russell Island vary from coarse sandy loams in the east to clay and silt loams in the west. Most of the till blanket samples are concentrated towards the finer grade boundaries of the loam division. Figure 4.12 shows that

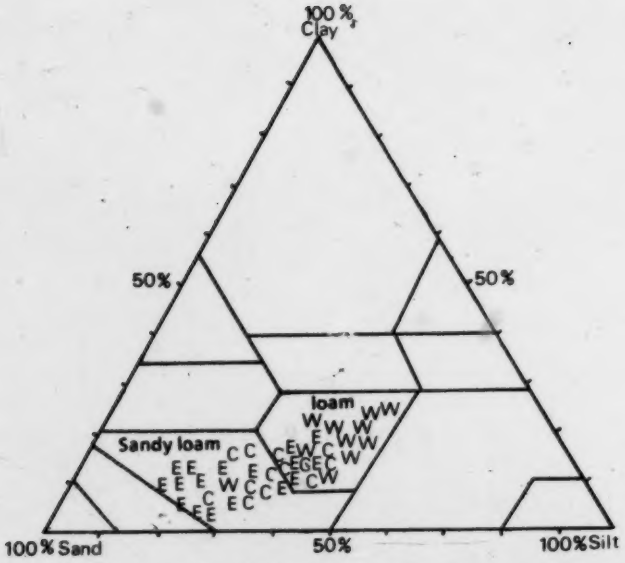


Eastern Till Blankets – E – on Sandstone Bedrock

Central Till Blankets – C – on Sandstone and Carbonate Bedrock

Western Till Blankets – W – on Carbonate Bedrock

Figure 4.11
Ternary diagram of till blanket textures from East, Central and West Russell Island.



Eastern Till Veneers — E — on Sandstone Bedrock

Central Till Veneers — C — on Sandstone and Carbonate Bedrock

Western Till Veneers — W — on Carbonate Bedrock

Figure 4.12
Ternary diagram of till veneer textures from East, Central and West Russell Island.

only a few till veneer samples in the west are plotted towards the finer boundaries of the loam classification. Most till veneer samples are concentrated at the coarser loam-sandy loam boundary.

The Russell Island till textures are closely related to those found by Scott (1976) who classified Russell Island within his Prairie-MacKenzie Province of till composition. The ternary diagram examples in Flint (1971) also accurately classify Russell Island tills as containing a mixture of limestone and dolomite with up to 60 percent clastic material. Therefore, the textures of Russell Island tills conform with regional geologic parameters.

Figures 4.13 and 4.14 illustrate superimposed groups of cumulative percentage, particle size curves for the till blankets and veneers from eastern, central and western Russell Island. The till blankets have a close assemblage of curves which indicates that they have relatively uniform textures. The till veneers from the same areas exhibit a greater variety of curves and appear to be more closely related to the underlying bedrock type. Although they fall into a similar textural classification, the family of eastern curves is quite distinct from the family of western curves in both diagrams and the central curves plot consistently between the other two. Therefore, despite changing directions of glacial flow, most of the till constituents were derived from the local bedrock.

The cumulative particle size curves are similar to examples given in Flint (1971) and clearly fall into the category of those derived from a sedimentary bedrock source. In most cases, the eastern till veneers are associated with a clastic source. Most of the eastern and central till blankets have characteristics of both sources. Again, this indicates distinctive genetic differences.

The sand content in the tills reaches almost 80 percent along the southeast coast of Russell Island (Fig. 4.15). Two plumes of high sand content extend towards the northwest, across the conglomerate and sandstone bedrock facies. The sand content appears to stabilize over the sandstone bedrock, maintaining just under 50 percent in the till veneers of the central-east part of the island. However, the sand content drops to less than 40 percent in the

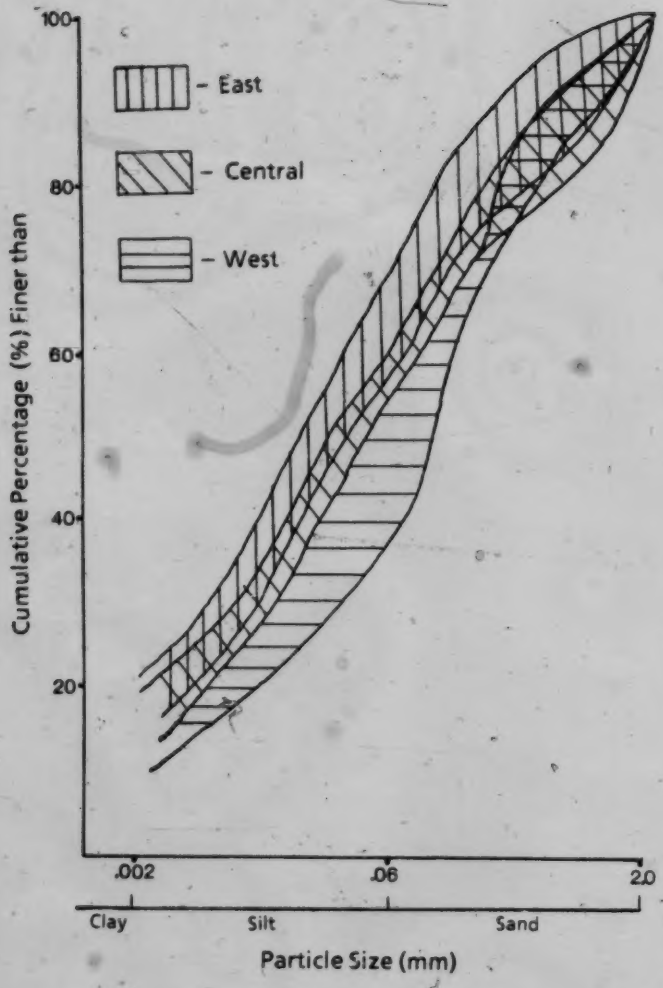


Figure 4.13
Superimposed till blankets cumulative percentage particle size curves from East, Central and West Russell Island.

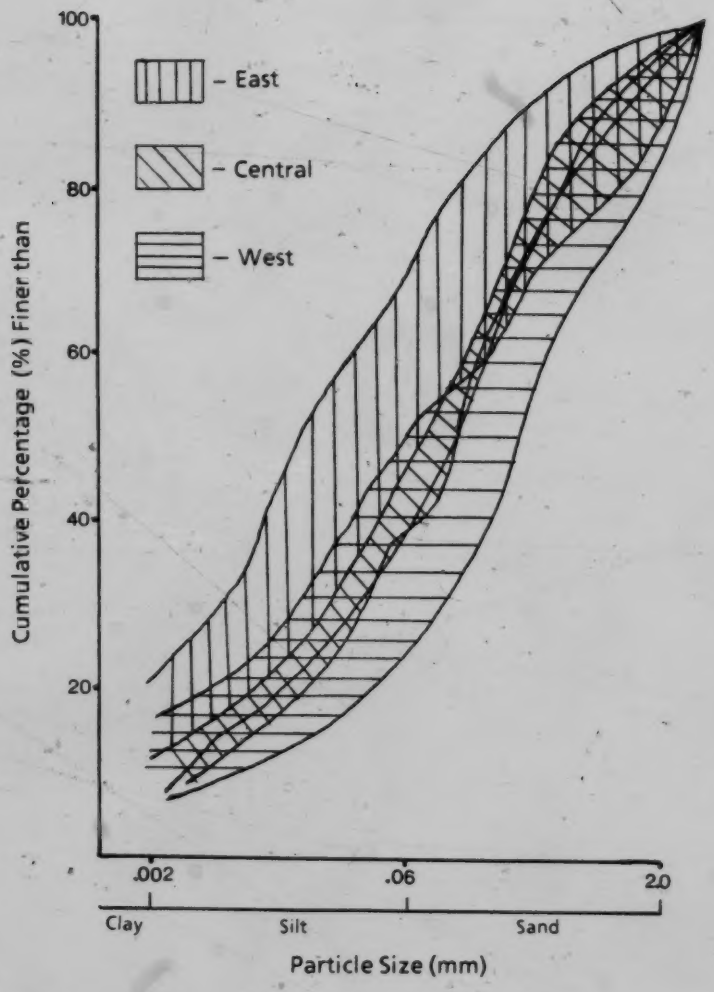


Figure 4.14
Superimposed till veneers cumulative percentage particle size curves from East, Central and West Russell Island.

Figure 4.15 Sand content (%) of the tills of Russell Island.

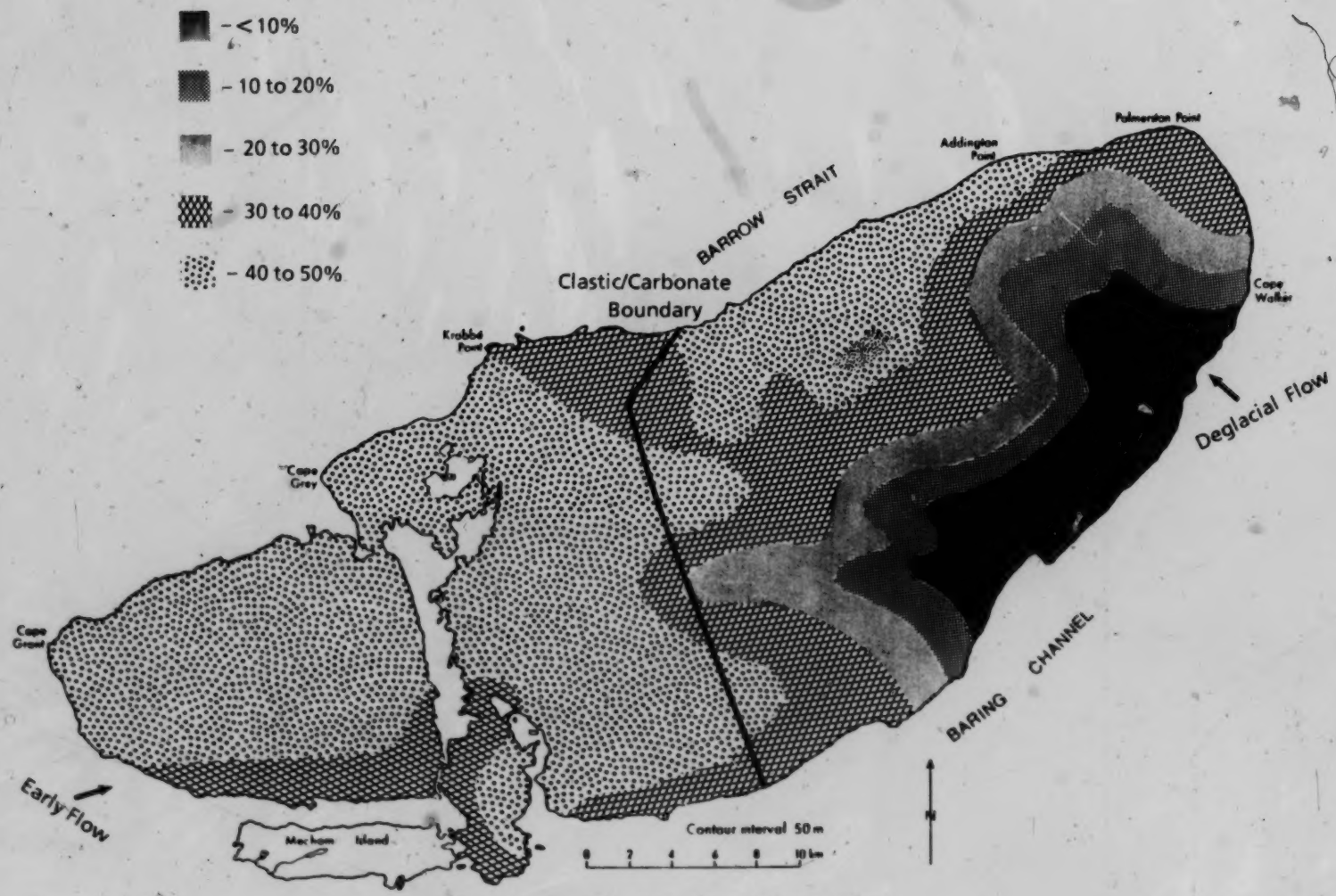


Figure 4.16 Silt content (%) of the tills of Russell Island.

Figure 4.17 Clay content (%) of the tills of Russell Island.

series of till blankets along the northeast coast. A distinct area of relatively lower sand content is also found directly over the conglomerate bedrock in the northeastern uplands. The lowest sand content (20 to 30 percent) is located in a narrow belt trending along the sandstone/carbonate lithologic boundary.

In western Russell Island, the sand content in the till is less variable. The highest content is 60 percent along the south coast. Northwards, the content steadily drops to just over 30 percent, east of Cape Grant, then rises again to about 45 percent along the rest of the northwest coast.

The silt content of the tills is negatively correlated with the sand content; the lowest percentages (<20 percent) are found along the southeast coast (Fig. 4.16). The two northwest trending plumes (with higher sand percentages) are particularly distinct as areas of low silt content. Silt content rises northward, reaching over 40 percent in the till blankets along the extreme northeast coast. One sample exceeds 50 percent silt. In the eastern uplands, in the same area that had a lower sand content in till over the conglomerate bedrock, there is a strong gradient with distinctly higher percentages of silt. In central Russell Island, the textural pattern fluctuates because wide plumes of higher and lower silt interfinger east and west of the clastic/carbonate boundary. The 40 to 50 percent silt division encompasses most of the western part of Russell Island except for the south coast which reaches only about 35 percent silt.

Figure 4.17 illustrates the clay content in the surface tills of Russell Island. As with silt, the lowest clay contents (4 percent) are found along the southeast coast of the island and increase steadily towards the north and northwest. A narrow tongue of lower clay, associated with higher sand content, extends northwestward through the till veneers of the eastern uplands and corresponds with strongly inscribed ice flow features. The anomalies of lower sand and higher silt in the eastern uplands and along the north-central coast are not distinct in the distribution of clay. The pattern becomes complex in the central part of the island as the gradients of clay percentage increase, reaching a high of 25 to 30 percent over the clastic/carbonate lithologic boundary. Several irregular tongues of till with variable clay content

cross eastward and westward of the boundary. curves west of the boundary.

The clay content is more uniform in tills covering the carbonate bedrock in western Russell Island. The tills along the southwest coast reach only 5 to 10 percent clay. The clay content rises slightly towards the northwest coast, reaching just over 20 percent in the till blankets, southeast of Cape Grant.

The nearly opposing glacial flow directions inscribed in bedrock striae suggest that the surface tills contain materials derived from various regional bedrock types. Although the majority of the surface tills have acquired a loamy texture, they also clearly reflect the influence of local carbonate or clastic sources. The relatively wide and systematic changes in till textures on Russell Island therefore indicate that the successive glacial flows have not strongly modified the direct relationship between the tills and the underlying bedrock.

Both the ternary diagrams and the cumulative particle size curves demonstrated the till-bedrock relationship. They also revealed a textural contrast between the till veneers and blankets. In fact, in many cases, there appears to be greater variation between till thickness than from changing bedrock sources down flow-line. The veneers are generally stonier with an abundance of local, angular clasts. The matrix of the veneers is usually more coarse and variable than the blankets. These genetic differences are probably best explained by contrasting modes of deposition. This interpretation is discussed in the till landforms section.

Figures 4.15, 4.16 and 4.17 can be interpreted as illustrating the effect of the changing direction of ice flow on the pattern of till texture over Russell Island. The earliest flow transported fine-grained carbonate material eastward over the sandstone and conglomerate bedrock. The later deglacial flows were relatively short-lived, smearing coarser clastic material towards the north and northwest, only partially masking the early dispersal patterns.

Eastward transport of material could explain a major feature illustrated in Figure 4.15 because the sand content in many of the western tills overlying carbonate bedrock is consistent with the content found in the central, northeastern and eastern tills which overlie sandstone and conglomerate bedrock. The lowest sand content in the Russell Island tills is found parallel to

the clastic/carbonate boundary. The lower values extend eastward over the sandstone, indicating transportation of finer material from the west. The till blankets along the northeast coast and the till veneers in the eastern uplands also have noticeably lower sand contents, suggesting that much of their matrix composition was derived from the west and not masked or displaced by later flows.

The later deglacial flows are clearly indicated by two plumes of higher sand content extending towards the northwest through eastern Russell Island. These plumes influence only the proximal, eastern part of Russell Island as the sand content rapidly drops by 40 percent within 12 km in the direction of flow. The larger eastern plume is associated with the axis of a major valley. Ice flowing up this valley probably excavated remnant fluvial sediments along with the clastic bedrock, dispersing it in the till veneers of the eastern plateau. The other plume is associated with coarse material incorporated by a northwestward flow through several large divergent valleys. Evidence for the transitory nature of the deglacial flows is therefore demonstrated by the inability to remove the early distribution of western material, the strong topographic control on the incorporation of clastic debris and the distinct but nevertheless limited dispersal of that debris.

The distribution of silt in Figure 4.16 reaffirms the interpretations made previously for the distribution of sand. The deglacial till plumes composed of local clastic material are defined by their lower silt content. Beyond the influence of these plumes, the silt content is relatively uniform in central and eastern Russell Island where it was derived from the early dispersal of western carbonate material. The variable silt content along the clastic/carbonate boundary is taken as evidence of the local exchange of opposing source materials transported by the different glacial flows. The morainal ridges along the northeast coast, and the till veneers in the eastern uplands, are again similar to samples with high silt content overlying dolomite in the far western part of the island. The fact that a strong western character exists in the matrices of these eastern till blankets and upland till veneers indicates that they were deposited differently from the veneers to the south and that the composition of the tills beyond the sand plumes was

not stongly modified by the deglacial flow. In western Russell Island, the northwest deglacial flow has not noticeably influenced the uniformly high silt content of the tills.

Although the range of values is less extreme for clay than for sand and silt, similar conclusions concerning the glacial history can be made from the distribution of clay in the till samples (Fig. 4.17). The earlier eastward transportation of material is suggested by the relatively high clay content of till overlying conglomerate bedrock on the eastern uplands and sandstone bedrock just east of the clastic/carbonate boundary. Again, the influence of the coarser deglacial plumes is outlined through the southeastern part of Russell Island, diminishing rapidly towards the northwest. The textural pattern along the clastic/carbonate boundary exhibits the smearing and blending of materials derived from both western and eastern lithologies. Clearly, deglacial flows could not remove or totally mask the finer material previously transported from the west. The higher clay content of the till blankets along the far west coast is associated with a significantly lower sand content trending eastwards from Cape Grant and possibly indicates that fine-grained bedrock was incorporated by the eastward flow, accumulating immediately down-ice of the obstructing bluffs. Because these tills with high clay content were not observed to contain shell fragments, this may suggest that this clay is not of marine origin. However, Fossiliferous tills from the last glacial advance are common on Somerset Island (Dyke, 1983).

4.2.4 Carbonate Content

Dreimanis and Reavely (1953) first used carbonate content to distinguish between tills and determine past ice movements along the north shore of Lake Erie. Dreimanis (1960, 1961) expanded this research and used till carbonate content to assist in the identification of provenances and the reconstruction of the Late Wisconsinan glacial history of Southern Ontario. Similarly, because calcite and dolomite are primarily derived from the western bedrock of Russell Island, the carbonate content of the till samples was determined in order to identify patterns of glacial flow and drift dispersal.

Figures 4.18 and 4.19 contrast the carbonate contents found in till blankets and veneers in different parts of the island. The samples vary considerably but are divided into three main divisions: east, central and west, based on underlying bedrock facies belts.

Both of the till thickness categories exhibit successively greater carbonate content towards the west: ranging from 0 to 30 percent in the east; 0 to 40 percent in the central areas; to 0 to 60 in the west. As expected, the higher carbonate contents are found in tills overlying carbonate bedrock. Generally, the thicker tills appear to have a higher and more uniform carbonate content on Russell Island. This is possibly due to glaciological factors or postglacial leaching.

Figures 4.20 and 4.21 illustrate the areal distribution of calcite and dolomite in the tills on Russell Island. Basically, the patterns are a function of glacial flows across the north-south lithological boundaries. The difference between the carbonate content of till blankets vs. veneers suggests that depositional environments also influence the pattern on a smaller scale, possibly creating spatial anomalies in the distribution of erratic material. The lowest calcite contents are found along the southeast coast where much of the till contains less than 1 percent calcite (Fig. 4.20). Most of the till in the eastern part of Russell Island contains less than 5 percent calcite (Fig. 4.20). Slightly higher calcite concentrations occur in the till veneers of the eastern uplands (5 to 6 percent) and the till blankets along the northeast coast (6 to 10 percent). The 5 to 10 percent division crosses the clastic/carbonate boundary throughout central Russell Island. From there, the calcite content rises steadily towards the west, reaching almost 35 percent in the till blankets on the northwest coast.

The pattern of dolomite content in the tills is quite different from that of calcite (Fig. 4.21). For instance, the background percentages are much higher; the lowest dolomite contents along the southeast coast are more than 5 percent. The till veneers on conglomerate bedrock in the eastern uplands are high in dolomite, reaching 30 percent which is similar to the tills overlying dolomite in the west of the island. The till blankets along the northeast coast reach 16 to 20 percent dolomite, a division which also extends well into western Russell Island. The

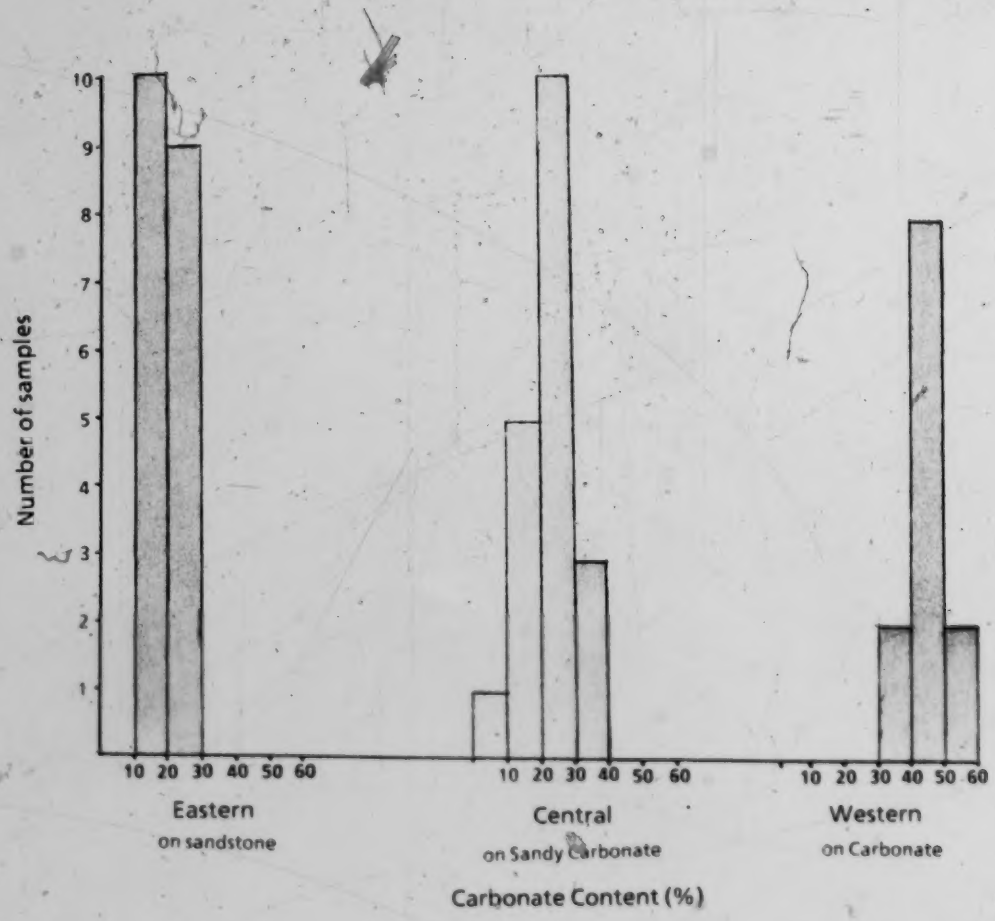


Figure 4.18 Total carbonate contents of the matrix of till blankets of East, Central and West Russell Island.

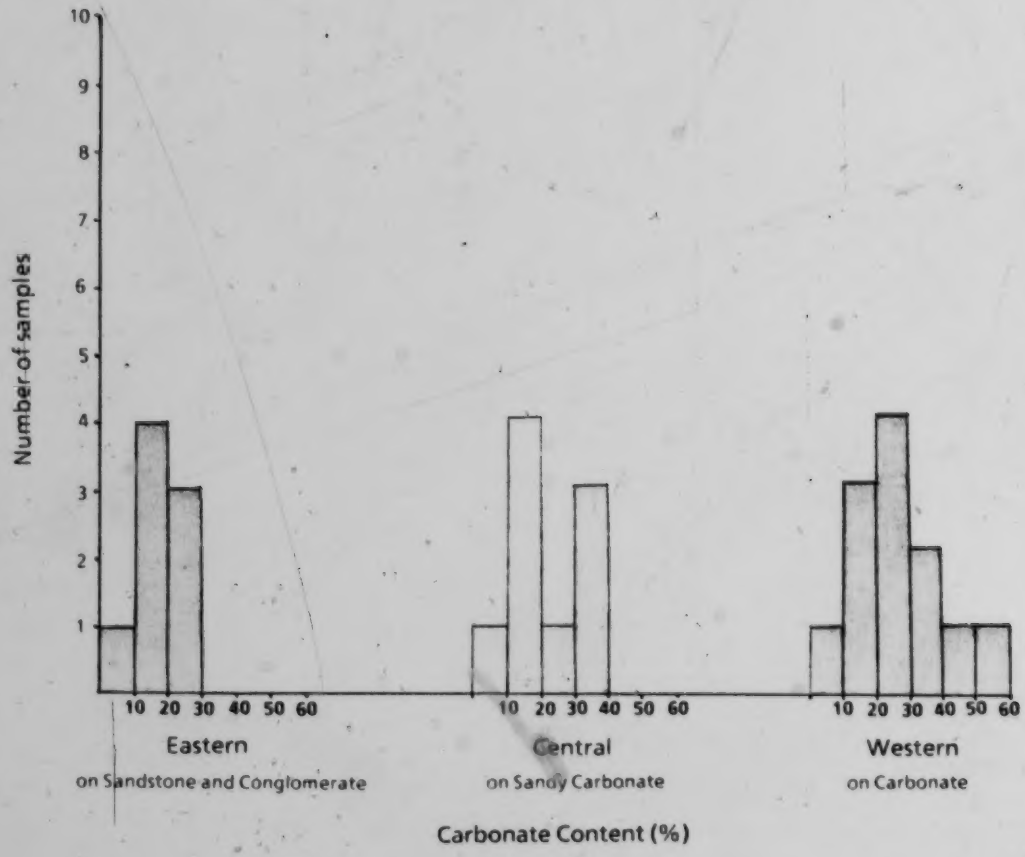


Figure 4.19 Total carbonate contents of the matrix of till veneers of East, Central and West Russell Island.

Figure 4.20 Calcite content of the tills of Russell Island.

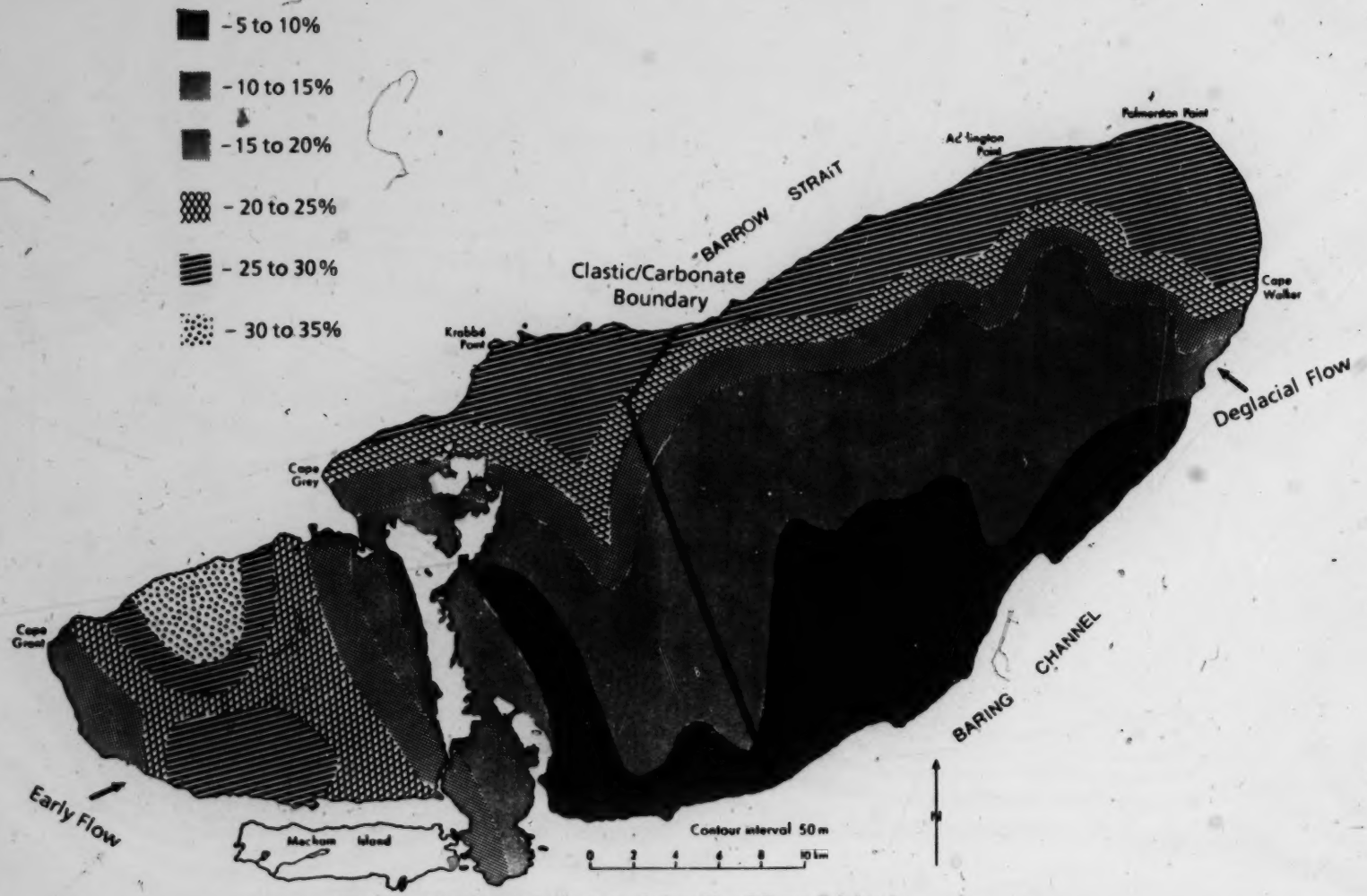


Figure 4.21 Dolomite content of the tills of Russell Island.

dolomite content is also relatively uniform on either side of the clastic/carbonate boundary. A narrow tongue of lower dolomite extends towards the northwest in the western lowland. Another corridor of high dolomite content also trends northwest/southeast through the westernmost part of the island.

The pattern of glacial flows indicated by the distribution of both calcite and dolomite is similar to that indicated by the till textures. The early eastward flow is best demonstrated by the distribution of dolomite, the dominant bedrock of western Russell Island. The dolomite extends roughly at right angles to the lithologic boundaries in the central and eastern areas and diminishes towards the southeast. This indicates the transport of western lithologies to eastern Russell Island. The dolomite pattern appears to show a greater spread of material along the Barrow Strait coast relative to Baring Channel. The isolated, high dolomite in the eastern uplands clearly represent erratic material from the west which was not strongly altered by the later deglacial flows.

The highest calcite values on western Russell Island are found as a splayed pattern in till blankets over dolomite bedrock (Fig. 4.20). This could indicate that the northwest deglacial flow excavated and incorporated material from the less resistant limestone beds in the lowlands and adjacent cuestas. The debris load in the ice was subsequently deposited as thick till blankets throughout the northwestern part of Russell Island. The western pattern of highest dolomite values suggests that the northwest deglacial flow crossed Mecham Island (Fig. 4.21) and incorporated dolomite from the bedrock bluffs on the southwest coast of Russell Island. The high dolomite content was spread down-ice of the bluffs through the central part of western Russell Island. The topography therefore appears to have exerted the primary control in the incorporation and resulting distribution of material.

4.2.5 Base Metal Content

Till geochemistry has been used to improve the reliability of till differentiation. For example, Roed (1968) found that a variety of heavy minerals, especially horneblende,

distinguished Laurentide and Cordilleran tills in western Alberta. Willman et al. (1966) used the presence of unweathered heavy minerals to provide a relative age and differentiate a series of time-stratigraphic tills in Illinois. Base metal concentrations from the clay fraction of tills have also been successfully employed for drift prospecting in the District of Keewatin by Shilts (1972, 1973, 1974, 1977). Dyke (1983) confirmed that samples collected from the active layer of tills show lateral variations in geochemistry that are in turn related to changing source materials and ice dispersal. For example, Dyke (1984) used base metal concentrations to outline the eastward dispersal trains that cross southern Somerset Island and northern Boothia Peninsula from the former M'Clintock Ice Divide. In this study, base metal concentrations in the Russell Island tills are used to indicate till provenances, glacial flow patterns and to further characterize till compositions. The results serve to reinforce the conclusions of the previous analyses.

The base metal analyses indicated that zinc, nickel and chromium have the greatest variability and most interesting anomalies. Figure 4.22 displays histograms of frequency (number of samples) vs. concentration for the three base metals. In the histograms, anomalous samples are the isolated bars with metal concentrations above the background values. The boundary between the anomalous and background values is about 130 ppm for zinc and 100 ppm for nickel and chromium.

The distribution of zinc, nickel and chromium concentrations in the tills of Russell Island are also mapped (Figures 4.23, 4.24, 4.25). High values are clustered in two areas: a zinc anomaly occurs within the till blankets of northwest Russell Island, east of Cape Grant, whereas nickel and chromium anomalies occur within the tills at the margins of the eastern uplands. One sample in the zinc anomaly reaches 340 ppm and two more are over 230 ppm. The two highest nickel anomalies reach 125 ppm and samples from the same area contain anomalous chromium levels up to 220 ppm.

Only general conclusions can be drawn from the base metal content in the tills. The western zinc anomaly appears to be derived from the cuestas of the south coast or western

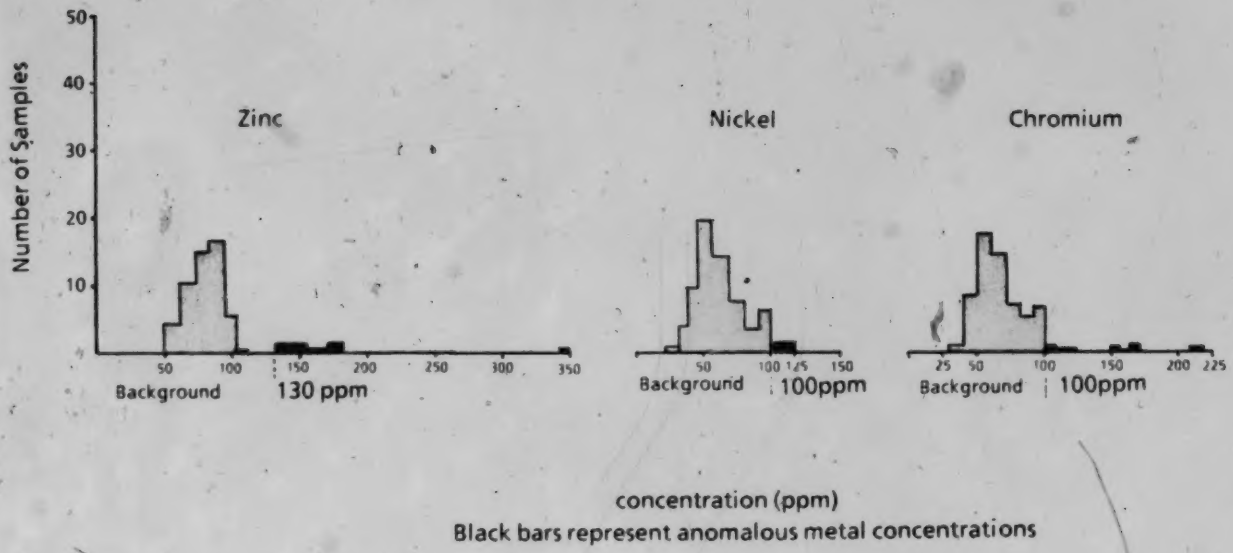


Figure 4.22

Histograms of zinc, nickel and chromium concentrations (ppm) in the <2mm fraction of the till samples of Russell Island.

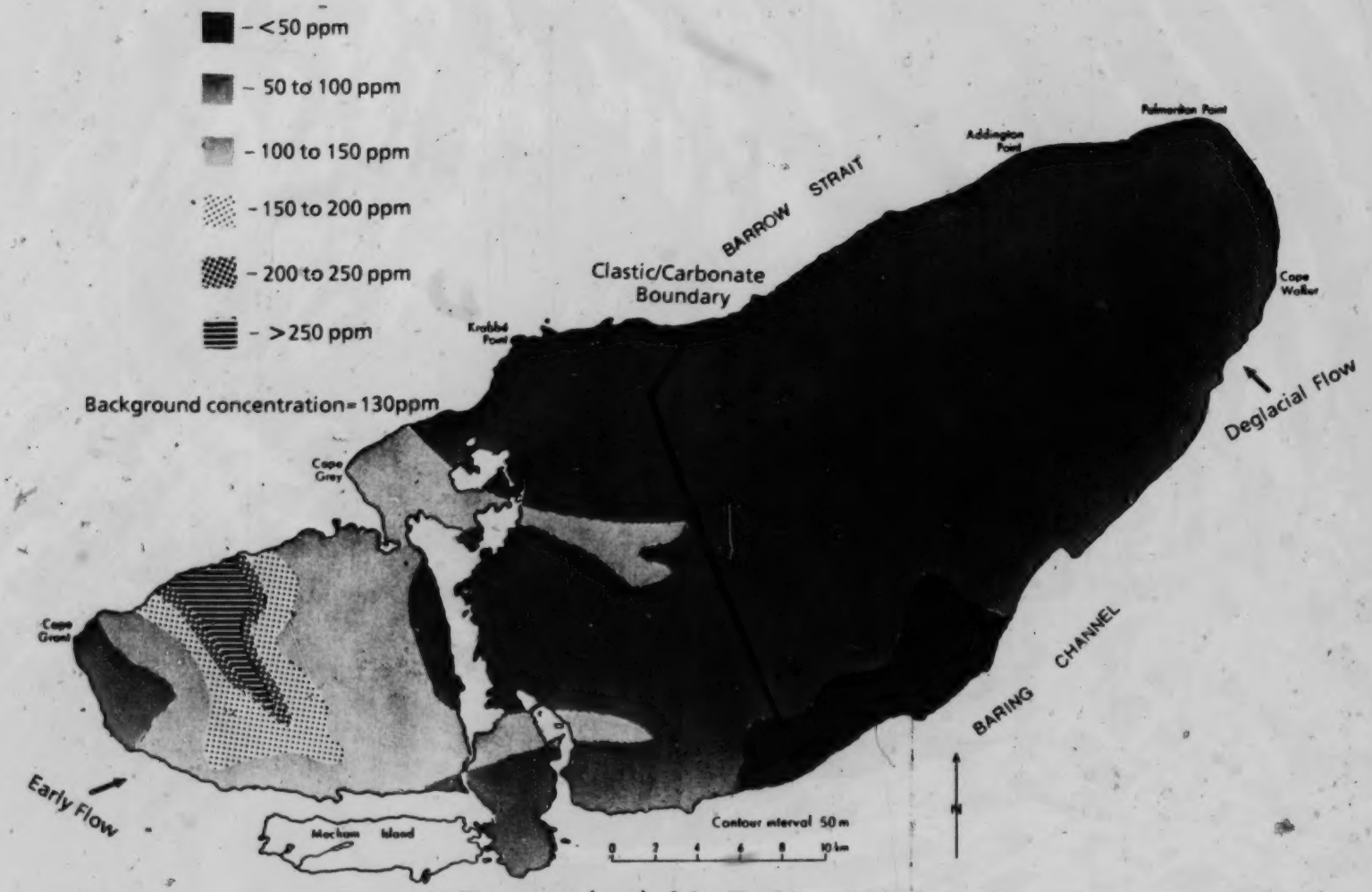


Figure 4.23 Zinc content (ppm) of the tills of Russell Island.

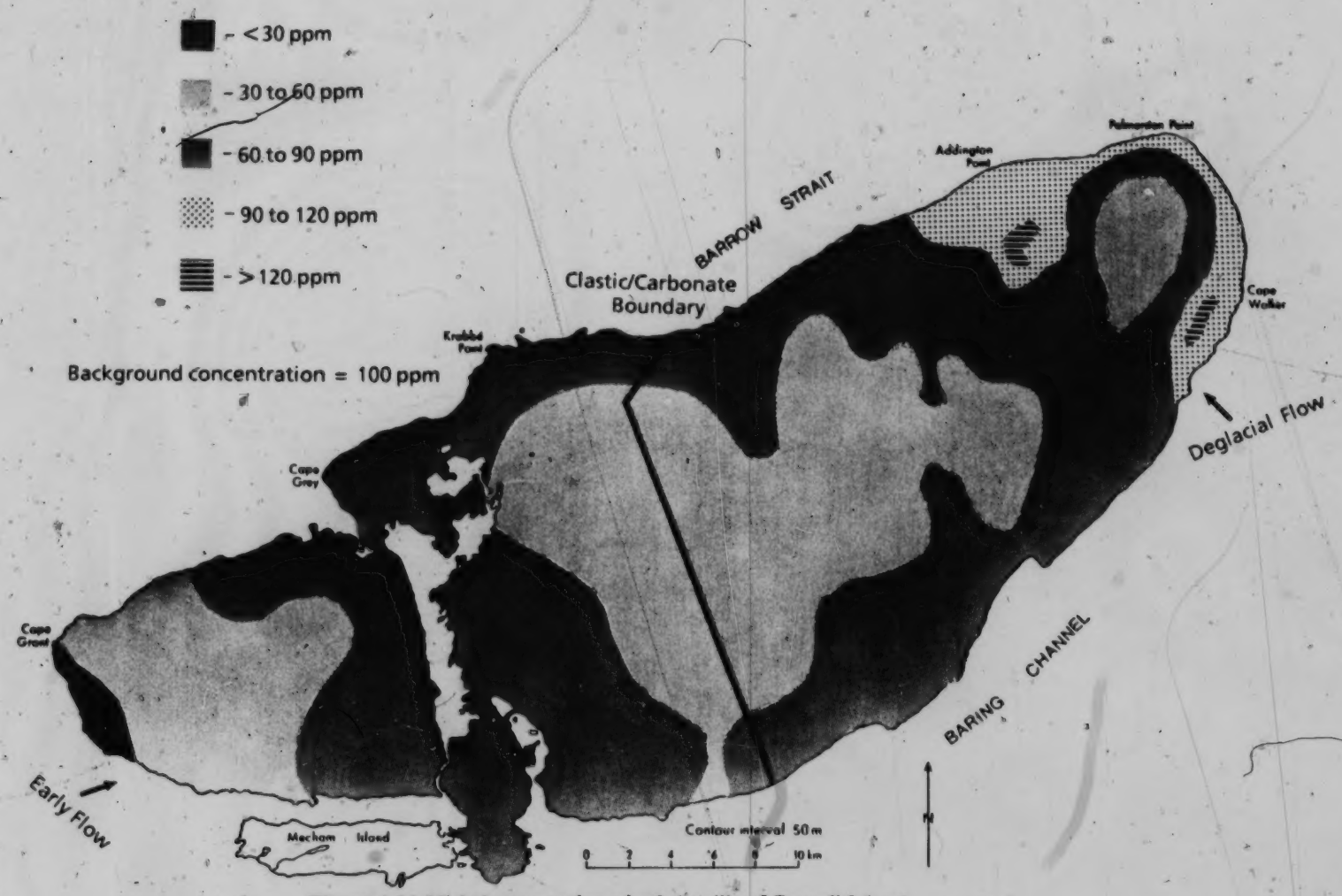


Figure 4.24 Nickel content (ppm) of the tills of Russell Island.

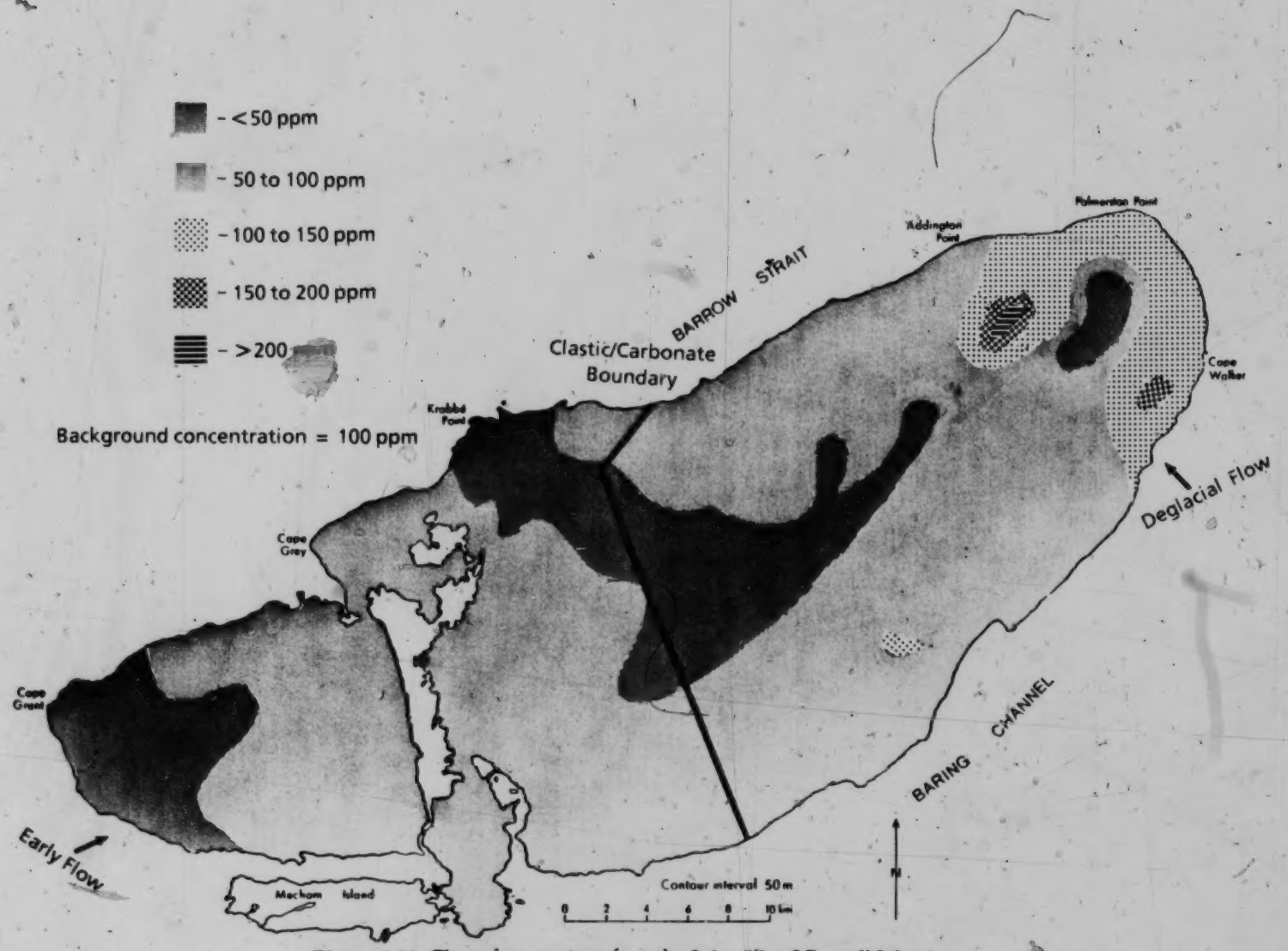


Figure 4.25 Chromium content (ppm) of the tills of Russell Island.

lowland which are also the sources for the most calcite-rich till. From there, the early, eastward flow transported till with higher zinc (100 to 150 ppm) over the sandstone lithofacies (Fig. 4.23). The deglacial flows more recently excavated the cuestas and spread the material in a northwest train through the western till blankets (Fig. 4.23). The anomaly has an abrupt western boundary indicating that the source is isolated and that the deglacial flow did not widely disperse the till with high zinc values. The deglacial flows also partially masked the eastern boundary of the zinc anomaly previously dispersed by the eastward flow.

Both nickel and chromium anomalies are isolated within the same till samples and are likely derived from the same ultrabasic, plutonic rock that occurs locally. Therefore, the nickel and chromium are not considered to be from a distant source such as the crystalline bedrock of eastern Prince of Wales Island, 100 km to the south, but rather from a local source such as the diabase/gabbro clasts in the Peel Sound conglomerate.

Figures 4.24 and 4.25 outline two till compositions in eastern Russell Island. The nickel and chromium anomolies are in till strongly influenced by the northwest deglacial flow. They are lower in calcite, dolomite, silt and clay. Between the anomalies is a tongue of till with nickel and chromium background values similar to those in the west. This tongue is also apparent on the maps of carbonate and texture surrounded by the deglacial-till plumes. Although the coarse fractions of the tills within the tongue are dominantly derived from local conglomerate and sandstone, the matrix fractions clearly contain erratic carbonate material from the west. Hence the tongue is considered to mark the earlier eastward flow pattern that has not been entirely erased by the short-lived deglacial flows. The till veneer samples from the tongue are in the higher parts of the eastern uplands, east of the topographically controlled deglacial plumes. Their position indicates that they could have been protected by the southeastern cliffs and upland outcrops of Russell Island.

4.2.6 Conclusions on Till Analyses

The mapping of Russell Island till characteristics indicates that the matrix exhibits regional characteristics whereas the coarse fraction (clasts) primarily reflects changes in local bedrock. The earlier eastward glacial flow is demonstrated by the distribution of till textures, carbonate content and base metals whereas the northwest deglacial flows did little to rework and mask these earlier till patterns. This is not surprising because it is unlikely that there was any break in ice cover and because the deglacial flows were of shorter duration. The principal effect of the deglacial flows is manifested in the coarse components of the Russell Island tills. In this case, the patterns of sand content, clastic and carbonate clasts features a dominant northwest spread of materials, no more than 6 km beyond their respective lithologic boundaries, onto the earlier eastward dispersal. The lengthy eastward flow transported western carbonate clasts completely across eastern Russell Island but the lack of sandstone clasts in western tills verifies the short-lived nature of the northwestward deglacial flow.

4.3 Glacial and Post-Glacial Landforms

This section describes the late-glacial and post-glacial landforms of Russell Island which are mapped on Figure 4.1. Eroded bedrock landforms were discussed previously in order to introduce glacial flow patterns prior to the results of till analyses.

4.3.1 Flutings and Moraines

This subsection briefly discusses the landforms of the Russell Island till sheets using data from field mapping (see Fig. 4.1) together with the characteristics distinguished in the till analyses. Emphasis is placed on the genetic aspects of specific landforms as a prelude to the reconstruction of glacial dynamics in Chapter Six.

The basal genesis of many till veneers is indicated by flutings found on the uplands along the east coast of Russell Island. These flutings are up to 2 m high and 0.5 km long and are oriented towards the northwest from the deglacial flow. They were probably formed by

processes similar to those outlined by Boulton (1976) in which saturated basal debris was forced into cavities. In this case, the cavities would have been located on the lee side of the east coast cliffs.

In contrast to the active deposition of till veneers, till blankets are deposited under stagnant conditions during glacial retreat. For example, thick tills were deposited over the upland of western Russell Island, down-ice from the western lowland where there was erosion and transport of large volumes of carbonate bedrock by the northwest deglacial flow. The deposition of this till blanket is characterized by a number of kettle lakes, up to 1.5 km wide, oriented in a northeast-southwest direction through the central part of the till blanket. This indicates that during deglaciation in western Russell Island, ice stagnated, releasing till by mass wastage and melt-out processes.

A series of till ridges oriented northeast-southwest are found on the till blankets, east of the main lake in the western lowland of Russell Island (Fig. 4.26). These ridges are uniformly between 2-3 m in height, closely spaced and sinuous. They are composed of till deposited below the postglacial marine limit and some parts of them are mantled with beach gravel. The ridges are considered to be DeGeer Moraines and they may represent annual stands of the ice front as it retreated southwards in the marine embayment that occupied the western lowland.

The higher morainal ridges at the west coast, and across the north-central/northeast coast, mark more lengthy stands of the retreating ice front. The north coast ridges are best developed, reaching 40 m in height. They are generally oriented northeast-southwest and are interrupted by two major meltwater channels.

In the early stages of deglaciation on Russell Island, the ice front was rapidly calving into the sea along the north coast. Above marine limit, between Krabbe and Addington Points (Fig. 4.1), the ice front deposited large volumes of till. The resulting till blankets comprise a series of subparallel ridges, representing a number of ice front positions. Collectively, these ridges can be considered as one end moraine system. This end moraine surface is smooth and

Figure 4.26 Aerial view of the western lowland of Russell Island. DeGeer moraines are identified by the sinuous black lines east of the main lake.

gently undulating (Fig. 4.27). Meltwater was channeled into spillways and apparently assumed a small role in the construction of the moraine. A number of small, round kettles indicate that ice blocks were buried by mass wastage or till as the ice front retreated southwards. Subsequent solifluction and soil creep could have contributed to a more subdued end moraine morphology.

Laboratory analyses of the till from the end moraine demonstrated that it contains substantial quantities of erratic material. The tills are finer grained, more calcareous and contain more western carbonate clasts than the veneers which overlie similar sandstone bedrock to the south. This western carbonate material must have been transported over the sandstone bedrock by the early, eastward glacial flow. Subsequently, the northwest deglacial flow redirected the material and deposited it at the ice front on the north coast. The end moraine therefore is composed of erratic material that represents redirected englacial debris above the sandstone bedrock whereas the till veneers represent more local bedrock that was transported only a short distance by the deglacial flow. Following the formation of the north coast end moraine, the ice front retreated rapidly to the southeast and left no other end moraines.

The reworking of till material by successive glacial flows has been noted in other areas by Peck and Reed (1954), Droste and Doehler (1957), Gross and Moran (1971) and Shilts (1973). In this case, the shifting ice flows occurred during the Late Wisconsinan and there was no break in ice coverage. Therefore, the resulting tills have retained the prominent characteristics of both source areas whose strengths are reflected mainly in terms of the respective durations of the flows (east vs. northwest).

4.3.2 Glaciofluvial Landforms

There are two groups of glaciofluvial sediments on Russell Island: ice-contact stratified drift and proglacial outwash. Both were sorted and deposited by glacial meltwater. The ice-contact deposits include kame terraces, various sizes of conical, moulin kames and eskers. Proglacial outwash is limited to a fan associated with a subglacial meltwater channel and an outwash plain related to a kame complex in the central uplands.

Figure 4.27 End moraine surface on north-central Russell Island. This moraine is subsequently cut through by two large spillways which extend from later stagnant ice marked by kames, 3 km to the south

The largest glaciofluvial deposits occur in the central kame complex, 3 km south of the end moraine on north-central Russell Island (Fig. 4.1). The kame complex is arranged in terraces and conical hills with intermediate kettle lakes. These kames consist almost entirely of local, platy, red sandstone clasts. The kame complex occurs on the drainage divide at the source of a large bedrock meltwater channel which extends several kilometres southward to a steep-sided, preglacial bedrock channel contacting with a large alluvial fan at about 90 m asl. (Fig. 4.28). There, thick deposits of glaciomarine sediments accumulated along the south coast between 80 and 20 m asl. Northward from the kame complex, the bedrock meltwater channel immediately diverges northwestward and northeastward into two prominent spillways (Fig. 4.1). These spillways vary in size but they reach 20 m deep, 300 m wide and 5 km in length. Their channels are constricted by bedrock through the kame deposits whereas they broaden and curve through the till blankets (Fig. 4.29). Finally they join more narrow, preglacial bedrock valleys in which they were forced to terminate near the uppermost shorelines (100 m asl). Any deltas formed within the narrow bedrock channel were removed by subsequent erosion during the postglacial period.

A proglacial outwash plain, approximately 1 km^2 in area is located adjacent to the kame complex (Fig. 4.1). During deglaciation of the area, large volumes of meltwater drained from the kames, transporting debris from the retreating glacier. When the spillway abruptly broadened beyond the bedrock valley, the meltwater became braided on the till blanket where the outwash plain was deposited. The plain surface is dominantly composed of local, red sandstone cobbles and boulders with interstices filled by gravel and sand. Many of the larger cobbles appear imbricated by a northward flow. Recent fluvial activity has cut a small, straight channel through the centre of this outwash plain.

A large channel, interpreted as the product of subglacial meltwater, crosses central Russell Island, 16 km southeast of Krabbe Point (Fig. 4.1). The channel is about 2 km long, oriented northwest-southeast, with steep sides cutting 40 m through carbonate and sandstone bedrock (Fig. 4.30). The channel was eroded by meltwater at the glacier base when it covered

Figure 4.28 Southward view through the kame complex and bedrock spillway on the central uplands of Russell Island. Prince of Wales Island is in the background.

Figure 4.29 Former, northwestward-draining, spillway extending through till blanket on the north-central Russell Island uplands. This spillway is evident on Figure 4.1 where it trends northeast from the upland kame complex.

Figure 4.30 Subglacial meltwater channel on the drainage divide on central Russell Island.

the drainage divide. A proglacial outwash fan covering ca. 500 m² was created as the ice-front stood on the south side of the divide and meltwater briefly drained subaerially through the channel which had become exposed by the retreating ice (Fig. 4.1). The outwash fan is gently sloping, irregularly shaped and composed of locally derived sand to rounded boulders. Recent stream drainage is dissecting and reworking the eastern part of the fan.

Small moulin kames are found in groups through the eastern uplands of Russell Island. These consist of conical hills of sand and gravel ranging from 3 to 10 m high. The largest group is found in northeast Russell Island on the till veneers, 3 km southwest of Palmerston Point (Fig. 4.1). Most of these kames are isolated hills up to 6 m high but two are connected by a short, sharp ridge of sand and gravel, 100 m long, forming either an esker or a crevasse filling. A number of kames border small, round kettles suggesting ice stagnation (Fig. 4.31). The kames are composed primarily of well-rounded pebbles derived from the conglomerate bedrock, 2 km to the east. The alignment of these kames suggests that they are associated with the main end moraine system.

Another group of kames occurs on the till veneers in the uplands, 12 km west of Cape Walker (Fig. 4.1). Three main conical kames stand about 25 m apart, 8 to 10 m in height and 20 m in diameter. They are composed of crudely stratified, coarse sand and slightly rounded sandstone pebbles, similar to the underlying bedrock. The sands are horizontally-bedded indicating high stream velocities during deposition (Allen, 1970). These kames therefore represent local conditions of ice front stagnation and disintegration as the glacier stood to the east.

Eskers are the most common ice-contact glaciofluvial sediments on Russell Island. The largest esker is found on the north-central coast of the island between Krabbe and Addington points (Fig. 4.1). It is over 2 km long and reaches 20 m high (Fig. 4.32). The locally sinuous esker ridge originates close to the uppermost shorelines (96 m asl) and ends with a steep snout at 15 m asl. The esker is composed of local sandstone clasts with platy shapes. There are also scattered patches of rounded carbonate clasts. It is oriented towards the northwest, parallel to

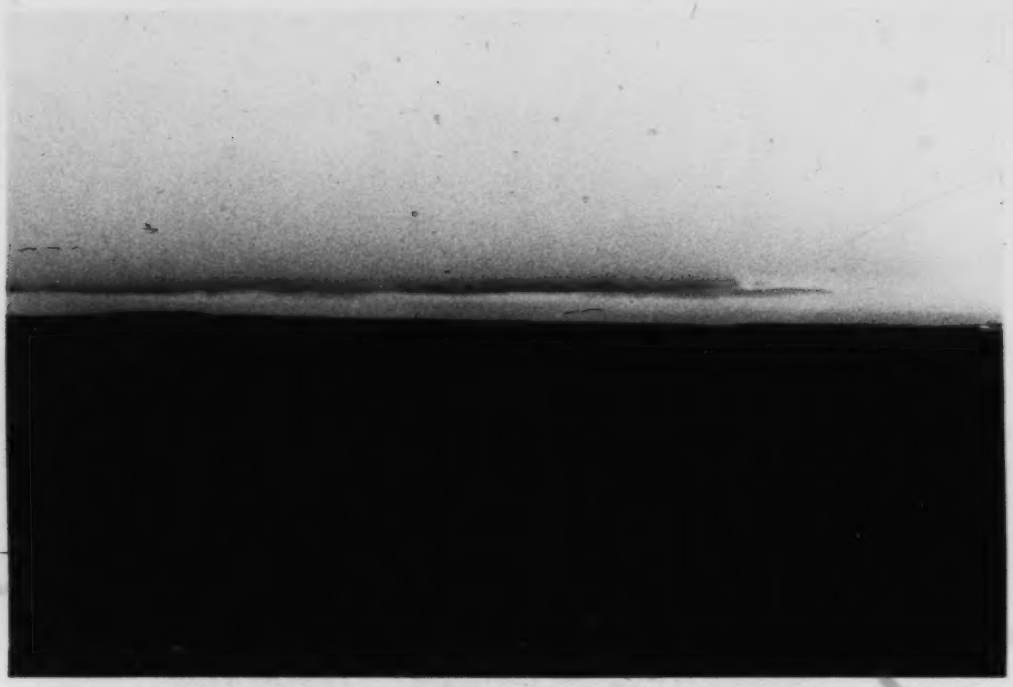


Figure 4.31 Kames from 2 to 6 metres high with intervening kettles on the eastern uplands of Russell Island. These features mark former ice stagnation.

Figure 4.32 North coast ice-directional esker superimposed by conspicuous raised beaches.

the active ice flow during the early stages of deglaciation on Russell Island. It is apparent that the location of the esker below marine limit indicates that it was formed by grounded ice.

Eight distinct eskers are found around and within the large lake occupying the western lowland of Russell Island. One esker enters the sea northeast of Mecham Island (Fig. 4.1). Of these, six of the eskers are ice-directional, oriented towards the northwest whereas three are oriented towards the west, parallel to the DeGeer moraines,possibly along former crevasses. All the eskers are composed of sand, gravel and cobbles derived from local carbonate bedrock. These lowland eskers are all shorter and lower than the one on the north-central coast, generally being less than 2 km long and 5 m high.

The abundance of eskers in the western lowland of Russell Island is probably due to two main conditions:1) a concentration of subglacial meltwater within the lowland; and 2) the rapid break up of the glacier in the lowland which allowed better preservation of the features. A concentration of eskers in low points in the subglacial topography has also been noted by DeGeer (1897) and Grano (1958) in Fenno-scandia.

4.3.3 Fine-grained Glaciomarine/marine Sediments and Landforms

As the glacier retreated, fine-grained material, mostly silts, settled in the nearshore marine environment. These silts probably consist of both material released by the wasting glacier (glaciomarine) and material such as redeposited till fines suspended by postglacial (nonglacial) wave agitation. Therefore, because these two sources are indistinguishable without thorough dating control, the raised silt sediments are mapped and discussed as a single unit, subdivided only by thickness.

Raised marine silts are preserved at three main sites on Russell Island: 1) the western lowland; 2) the south-central coast; 3) a small basin along the northwest coast of Russell Island. In the western lowland, 5 km south of Krabbe Point along the northeast arm of the main lake (Fig. 4.1), the silts are up to 3 m thick and overlie till. These silt blanket surfaces are covered with evenly spaced earth hummocks and a regular cover of moss (Sphagnum spp.).

They are also well gullied and their southern flank is being eroded by a river which is constructing an alluvial plain (Fig. 4.33). The silts contain abundant shells and are almost entirely stone-free. This suggests that ice-rafting was not active during their deposition which may reflect the presence of landfast summer sea ice at that time. The silts occur at 10 m asl which is at least 90 m below the local marine limit. A smaller, isolated silt blanket with numerous wet meadows and ponds is located on the coastal till plain, 2 km southeast of Krabbe Point (Fig. 4.1).

Most of the western lowland silts are less than 2 m thick. These silt veneers are located south of the silt blankets, along the eastern shore of the northeast arm of the main lake (Fig. 4.1). They overlie till blankets and are occasionally mantled with beach sand and gravel. These fine-grained sediments are particularly widespread in the western lowlands because it provided a sheltered marine basin, favouring the collection of fine glacial and reworked sediments.

Over 10 km^2 of raised silt veneer occurs on a coastal plain on the south-central coast of Russell Island (Fig. 4.1). The silt surface slopes gently southward from 80 m asl. (at least 20 m below local marine limit) to 20 m asl. and is well dissected by streams and gulleys. The central part of the silts is poorly drained with extensive wet meadows and ponds. The northern parts, adjacent to the uplands, contain a significant fine sand component but very few stones. There are also scattered patches of shells across this silt surface.

Like the deposits of the western lowlands, the south coast raised silts exist because they settled in a basin, protected from strong wave and current action. The topographic basin was created by a bedrock ridge which formed a sill 60 m in elevation parallel to the coast. Fine-grained sediments settled from the postglacial sea and collected between this ridge and the central uplands.

An area of raised silt veneer, less than 500 m^2 is found in a small lowland surrounded by bedrock and till ridges in the north-central part of western Russell Island (Fig. 4.1). These silts extend to 60 m asl (at least 45 m below local marine limit) and lie on a steeper slope than the other two deposits. A well incised stream drains northward from the silts forming a wide

Figure 4.33 Raised glaciomarine/marine silt blanket. View is southwards, across the western lowland of Russell Island, to the north coast of Prince of Wales Island in the background. Silts are generally <3 m thick and exposures are rare.

alluvial fan near sea level. In the eastern part, this has resulted in vigorous gullying which has formed isolated hummocks of silt about 10 m in diameter. These silts are slightly stoney and unfossiliferous.

4.3.4 Coarse-Grained Marine Sediments and Landforms

Following deglaciation, course-grained marine sediments formed deltas and beaches in the postglacial sea. Raised marine deltas are found at two locations on Russell Island: 1) along the south-central coast; and 2) within the prominent southwest inlet, 3 km east of Mecham Island (Fig. 4.1). Along the south-central coast, the deltas consist of sand and gravel topsets and foresets, 2 to 3 m thick. There are three distinct delta levels at approximately 25, 15 and 10 m asl. As the postglacial sea regressed below these levels, the deltas were incised by fluvial erosion. The marine delta in the southwest inlet consists of poorly developed, gravel topsets and foresets up to 2 m thick deposited at an elevation of 10 m asl. The relative lack of marine deltas on Russell Island indicates a paucity of sediment transported during the postglacial period. This could imply that the majority of the nearshore marine silts are glaciomarine rather than postglacial marine. It also argues against the availability of meltwater provided by late-lying, local ice on the island.

Raised marine beaches, on the other hand, are a common feature on Russell Island, comprising up to 20 percent of the land surface. The best beach development occurs below 30 m asl where sea level regression proceeded at a slower rate, perhaps during an interval of more reduced summer sea ice. Continuous flights of raised beaches form the uppermost shorelines (98 m asl) along the north coast where there was both greater fetch and sea ice impact through time.

Beach compositions reflect that of the underlying till. On the east coast, the beaches are composed of sand to cobble-sized material derived from till containing Peel Sound conglomerate clasts. These beaches form smooth, regular ridges and swales (Fig. 4.34). On the north-central and west coasts, the beaches are more rugged because they are composed of

Figure 4.34 Smooth flights of raised beaches along the east coast of Russell Island. The eastward view includes northwest Somerset Island in the far background across Peel Sound. Foreground shows soliflucting till.

subangular carbonate plates and blocks (Fig. 4.35). Beach terrain can be especially rugged if the underlying bedrock was exposed by wave action. Beaches rarely exceed 1 m in thickness because they armour the underlying parent till as they are formed. Exceptions are found immediately south and southeast of Krabbe Point where there are raised beaches, gravel bars and spits up to 3 m thick. At present sea level, sea ice appears to dominate the beach forming processes, transporting littoral material and creating ice-push ridges. Sea ice processes have been described in other areas of the central Arctic (Taylor, 1978; McLaren, 1982).

4.3.5 Fluvial Sediments and Landforms

Fluvial sediments are subdivided into those in the present flood zone (active) and those deposited in terraces above the flood zone (inactive). On Russell Island, there are only small amounts of fluvial sediments due to the area's aridity, short stream flow season and permafrost in the stream bed. Although active fluvial sediments are found in the river and stream beds, they are mostly ephemeral. Where the rivers and streams emerge from confining upland valleys, fluvial deposition spreads laterally, forming alluvial fans. More than 30 alluvial fans were large enough to be mapped on Russell Island, ranging in size from about 100 m^2 to just under 1 km^2 (Fig. 4.1). The greatest concentrations of alluvial fans occur along the south coast and along the northwest plains of the western lowlands.

Alluvial plains are broad deposits of fluvial sediments spread over a braidplain. They are generally larger and lack the diagnostic cone-shape of alluvial fans. In the river profile, alluvial plains occur at low gradients, usually near sea level at the mouths of rivers with ephemeral discharge and seasonally high sediment loads. Five alluvial plains occur on Russell Island. The largest is located along the northeast arm of the main lake in the western lowland and it encompasses over 2 km^2 in area. It has a flat, smooth surface composed mostly of sand and silt derived from the local, fine-grained raised glaciomarine/marine deposits. Most of the alluvial plain is active only for a short duration of the year during the nival flood (Church, 1972) when the lake level is high. Three alluvial plains are located along the southeastern coast

Figure 4.35 Raised beaches developed from underlying carbonate bedrock at Cape Grant, northwest Russell Island.

of Russell Island. Two of these seashore alluvial plains are at the mouths of large rivers and one is positioned at the confluence of two smaller, separate rivers (Fig. 4.1). These alluvial plains are about 1 km² in area and are composed of fluvial sand and gravel. The sediments are deposited in broad flats and low longitudinal bars. During most of the summer only a small number of the channels have flowing water.

A small alluvial plain (ca. 500 m²) is located within the broad, former spillway where it passes through the end moraine in north-central Russell Island (Fig. 4.1). It formed through post-glacial time by periodic flooding and transportation of loose sediments from the kame complex and surrounding till blankets. The alluvial sediments collected across the plain as the gradient abruptly dropped beyond the constricted bedrock valley.

As the sea regressed during postglacial time, fluvial erosion was constantly rejuvenated, leaving parts of former floodplains perched above the active flood zone. There are only three examples of these now inactive alluvial terraces; on rivers entering the northeast arm of the large western lake and along the southeast coast. In each case, the terraces are composed of stratified sand and gravel and are located only a few metres above the active alluvial plains indicating that they were deposited under similar conditions.

5. THE POSTGLACIAL EMERGENCE OF RUSSELL ISLAND

This chapter contains an analysis of the postglacial emergence of Russell Island. The emergence is evaluated by constructing a composite emergence curve. Particular emphasis is placed on marine limit elevation and age. The emergence of Russell Island is then compared to neighbouring areas.

5.1 Background

In a simplified model, the earth can be conceptualized as having a thin, elastic crust overlying a viscous fluid. The elastic crust deforms instantaneously upon the application and release of glacial loads whereas the viscous component behaves as a plastic material, flowing at a rate proportional to the amount of stress and recovering slowly from deformation.

Coastal areas of the central Arctic emerged from the sea following the removal of the late Wisconsin ice sheets. The total isostatic recovery is considered to be contingent on three factors: 1) the reduction in the gravitational attraction of the ocean by the diminishing mass of the ice sheet; 2) the initial, elastic recovery of the crust from its previous glacioisostatic depression; and 3) the main non-elastic inflow of viscous mantle beneath the formerly depressed zone (Farrell and Clark, 1976). The effects of gravitational attraction and elastic recovery are essentially instantaneous whereas ongoing postglacial emergence is a function of the re-equilibration of the mantle.

Three elastic and non-elastic responses account for the total isostatic recovery at any given site during and after glacial unloading: restrained rebound, postglacial emergence and residual rebound (Andrews, 1970; Fig. 5.1). As an ice sheet begins to lose mass, there is an immediate elastic response and an accelerating non-elastic response. This initial recovery is termed restrained rebound because it occurs beneath an ice cover prior to deglaciation and the formation of the marine limit. The next period of glacioisostatic adjustment is called postglacial emergence which is initiated at the time of deglaciation. In most arctic areas, deglaciation is recorded by the initial entry of the sea which is marked by washing limits, beaches or deltas at

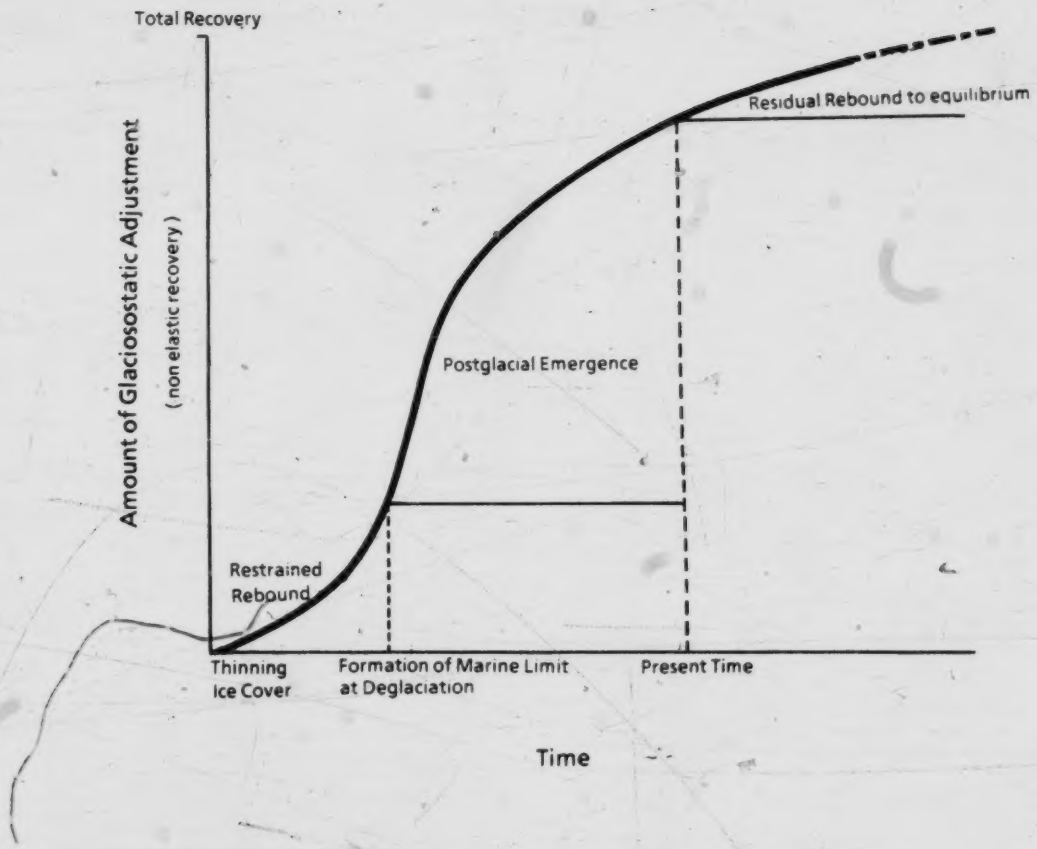


Figure 5.1 Periods of glacioisostatic recovery. Adapted from Andrews, 1970, p.14.

its uppermost extent, referred to as marine limit. During this postglacial period the rate of non-elastic recovery declines exponentially to present time. Historical records indicate that glacioisostatic recovery is still incomplete. This residual rebound is ongoing and will not be completed until isostatic equilibrium is reached in the mantle. Andrews (1969) extrapolated the late Holocene gradient of emergence curves to estimate residual rebound of 60 to 80 m in the central Arctic.

5.2 Uppermost Shorelines

Marine limit is the highest level reached by the postglacial sea at the instant of deglaciation. Because of this, marine limits form a time-transgressive surface and spatially, their ages record the pattern of ice recession. On a local scale, marine limits which rise towards the centre of former ice dispersal indicate rapid retreat of the ice front; relatively horizontal marine limits reflect moderate rates of ice retreat, ie. a balance between ice retreat and isostatic recovery; whereas declining marine limits indicate slow rates of deglaciation with greater restrained rebound. Therefore, the height of the marine limit is controlled by two principal factors which explain 68 percent of the variability in postglacial emergence (Andrews, 1968): 1) the distance from the former margin (ie. ice thickness); and 2) the time of deglaciation.

Two features mark the uppermost shorelines on Russell Island: 1) raised beaches; and 2) wave-washed till benches. The elevation of the highest shoreline on western Russell Island was significantly lower than expected for marine limit, based on the projection of shorelines from northwestern Prince of Wales Island (Dyke, in press,b). Whether it represents the marine limit is discussed later in the chapter.

At the north coast, between Krabbe and Addington Points, there are well defined, wave-cut notches (washing limits) and beach berms (Fig. 5.2). This washing limit is traceable over 19 km despite numerous stream and river valley gaps (see Fig. 4.1). Its elevation varies from about 96 m asl south of Addington Point to 98 m asl southeast of Krabbe Point. This surface records an average westward rise of only 10.5 cm/km and indicates that the ice front

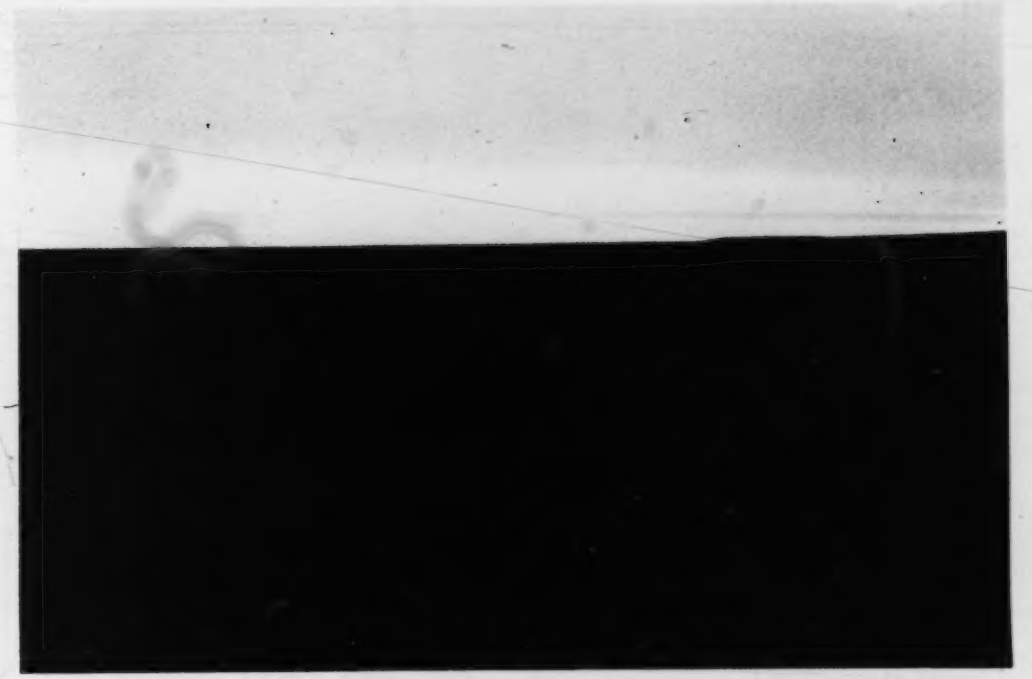


Figure 5.2 Wave-cut notch at 98 m asl on north-central Russell Island. The surface is near the projected elevation for local marine limit.

probably retreated uniformly from the north coast. The projection of marine limit elevations of between 95 m and 98 m asl from Cape Hardy, northeastern Prince of Wales Island indicates that this shoreline could represent local marine limit.

At the west coast, on the till blankets south of Cape Grant, and on a solitary hill at the south coast, east of Mecham Island, there are benches which were wave-washed into the till surface (Fig. 5.3). The west coast washing limit was measured at 108 m asl indicating that it had become ice-free and was emerging prior to the north coast. This shoreline extends 3 km in a north-south direction and its elevation is uniform. The isolated, wave-washed bench on the south coast was surveyed at 96.5 m asl. There are high raised beaches at the east coast but they are poorly defined, partially because of the limited space provided by the topography. Glaciomarine deltas were not found on Russell Island.

5.3 Age of Marine Limit

Radiocarbon dates on the marine limits (and/or uppermost shorelines) of Russell Island are unavailable, however, estimates can be extrapolated from sites on the adjacent coast of northern Prince of Wales Island. The 108 m shoreline on western Russell Island is across Baring Channel from a marine limit on Donnett Hill, Prince of Wales Island (see Fig 4.1; Fig. 5.6), dated at a minimum of 11,005 +/- 170 BP (S-2708). At that time, ice stood at the Donnett Hill moraine, covering areas above 200 m asl (Dyke, in press,b). Because ice remained at this elevation on northern Prince of Wales Island, it likely extended northward completely across Russell Island. Fifteen kilometres to the east of Donnett Hill, the sea entered a valley southwest of Arabella Bay (see Fig. 4.1;Fig. 5.6) by 10,435 +/- 160 BP (S-2709). Therefore, western Russell Island must have become ice-free sometime between 11,000 and 10,500 BP.

Based on a date of 9660 +/- 90 BP (GSC-3954) on the south side of Baring Channel, between Forsyth Point and Bellot Cliff (see Fig. 4.1;Fig. 5.6), and a date of 9845 +/- 150 BP (S-2710) south of Cape Hardy (see Fig. 5.6), the marine limit on northeast Russell Island must have formed between 9800 to 10,500 BP. Therefore, the glacial margin retreated from

Figure 5.3 Marine bench at 108 m asl cut into till blanket at the west coast of Russell Island. This feature is likely below the local marine limit.

northwest to southeast across Russell Island between roughly 10,800 and 9900 BP. If these estimated dates are correct, the ice front retreat rate would have averaged about 4 km/century.

5.4 Emergence Rates During and After Deglaciation

The difference in elevation between the highest washing limits on the west and east coasts of Russell Island should gauge the amount of differential emergence that occurred during the deglaciation of Russell Island. Using the estimated ages for these washing limits gives initial rates of emergence of about 5 m/century. These rates are much less than those found at Donnett Hill, Prince of Wales Island (9.6 m/century), Somerset Island (8 to 11 m/century) and Boothia Peninsula (14 to 30 m/century) (Dyke, 1983, 1984, in press,b). This indicates that either initial emergence on Russell Island was slower than surrounding areas or that the estimated ages and marine limit elevations are incorrect.

The rate of postglacial emergence since deglaciation can be plotted as a curve using: 1) the estimated ages of the highest washing limits; and 2) radiocarbon dates on lower relative sea levels (Fig. 5.4). Such an emergence curve represents the response to glacial unloading at a given site which should fall within an area of 100 km^2 or less for an accurate description of local emergence. Samples plotted from a larger area can be used for a generalized envelope of regional emergence. Emergence curves are used in this study primarily to compare the unloading histories between Russell Island and the adjacent coast of Prince of Wales Island.

5.5 Emergence Envelope

This section presents the postglacial emergence envelope from Russell Island using the available radiocarbon dated shorelines. At present, 19 samples have been radiocarbon dated on Russell Island (Table 5.1). Eleven samples of bone were submitted for dating to the Saskatchewan Research Council and five samples of wood and shells were submitted to the Geological Survey of Canada. Three other radiocarbon dates were previously obtained by other researchers of the G.S.C. Figure 5.5 illustrates the best fit composite emergence curves from

TABLE 5.1 RADIOCARBON DATES FROM RUSSELL ISLAND

	SITE	DATE (BP)	LAB NO.	MATERIAL (mm asl)	SITE ELEVATION (mm asl)	RELATED RELATIVE SEA LEVEL	LOCATION	REFERENCE
1.	S.E.Russell I.	9360±150	GSC-3994	Shells	84.5	>84.5	73°55'N 98°14'W	This Paper
2.	N.E.Russell I.	5910±195	S-2665	Seal bone	39.9	39.9	74°54'52"N 98° 9'00"W	This Paper
3.	E.Russell I.	5535±475	S-2668	Whale bone	36.7	36.7	74°00'42"N 97°39'W	This Paper
4.	N-C.Russell I.	5100±100	GSC-3999	Shells	12.0	>12.0	73°58'N 98°46'W	This Paper
5.	N.E.Russell I.	4510±165	S-2664	Whale bone	15.6	15.6	74°07'20"N 97°44'W	This Paper
6.	N-C Russell I.	3820±70	GSC-4002	Wood	14.7	14.7	74°02'N 98°34'W	This Paper
7.	E. Russell I.	3685±155	S-2671	Whale bone	10.8	10.8	74°01'20"N 97°37'30"W	This Paper
8.	N-C Russell I.	3675±110	S-2662	Whale bone	14.6	14.6	74°02'30"N 98°36'W	This Paper
9.	N.W.Russell I.	3630±60	GSC-2240	Wood	14.0	14.0	73°57'30"N 98°58'W	List XIX, p.41
10.	N.W.Russell I.	2950±60	GSC-3978	Wood	12.13	12.13	73°56'40"N 99°11'W	This Paper
11.	S.E.Russell I.	2590±140	S-2670	Whale bone	16.0	16.0	73°59'50"N 97°42'W	This Paper
12.	N.E.Russell I.	2250±60	GSC-4001	Wood	8.23	8.23	74°06'30"N 97°45'W	This Paper
13.	N.W.Russell I.	2075±135	S-2672	Tusk	9.0	9.0	73°56'N 99°17'30"W	This Paper
14.	N.W.Russell I.	1800±50	GSC-2300	Wood	5.7	5.7	73°57'25"N 98°58'30"W	List XIX, p.41
15.	N.E.Russell I.	1565±125*	S-2666	Whale bone	61.3	<61.3	74°00'30"N 98°03'30"W	This Paper
16.	N.E.Russell I.	620±235*	S-2663	Seal bone	25.4	<25.4	74°06'N 97°59'30"W	This Paper
17.	E.Russell I.	575±75	I-11769	Foxe bone	4.0	4.0	-	Ramsden, 1981 unpublished
18.	E.Russell I.	355±115*	S-2669	Seal bone	85.0	<85.0	74°02'30"N 97°38'W	This Paper
19.	N.E.Russell I.	400	S-2667	Whale bone	3.6	< 3.6	74°06'30"N 97°50'10"W	This Paper

* Sample age does not relate to the elevation at which it was collected.

Figure 5.4 The remains of a bowhead whale found at 14.6 m asl on north-central Russell Island. The bones were dated at 3675 +/- 110 BP and provided a control point on the late Holocene emergence curve from Russell Island.

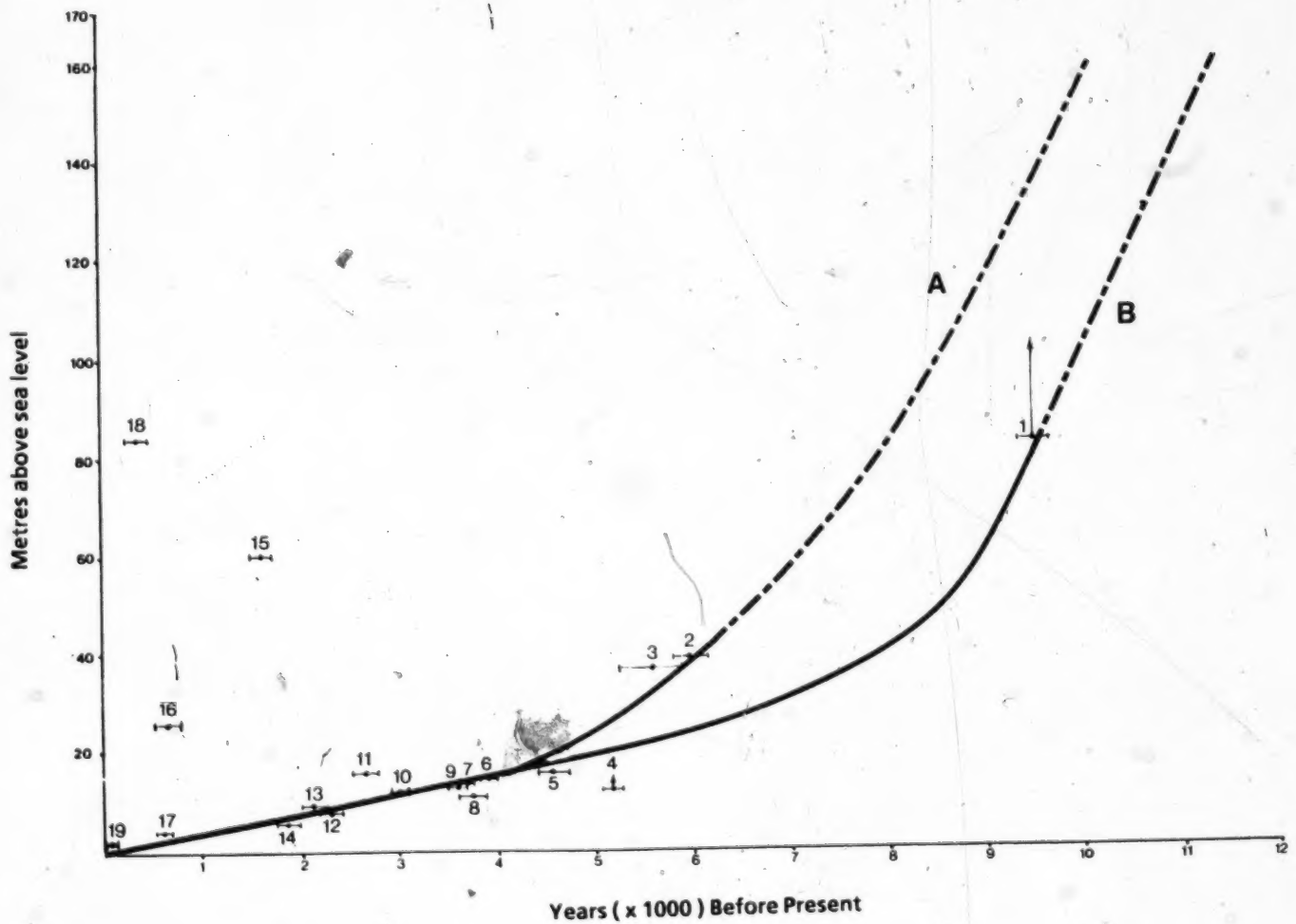


Figure 5.5 Preliminary postglacial emergence envelope for Russell Island. Numbers refer to descriptions in Table 5.1.

Russell Island. The resulting emergence envelope expresses the range in the rates of emergence provided by the available C^{14} dates from the island between deglaciation and the present. Because there are significant gaps in the curves, some sections had to be extrapolated. The form of the envelope between 5000 and 9300 BP is provisional and because the uppermost washing limits may be considerably lower than marine limit (unobserved), the curve represents a minimum slope. It may be much steeper.

The oldest radiocarbon date from Russell Island is 9360 +/- 150 BP (GSC-3994) obtained from a sample of shells collected on a till surface at 84.5 m asl on the southeast coast. The molluscs (Hiatella arctica) invaded the site sometime after deglaciation. Because they must have lived in some depth of water, the relative sea level at this time (9360 BP) stood an unknown height above 84.5 m (see Table 5.1). It is known that by 9360 BP, the retreating ice front occupied central Prince of Wales Island, about 150 km to the south.

The 9360 +/- 150 BP date provides a minimum estimate on the upper part of the Russell Island emergence envelope. Four in-situ bones, collected from 85, 61.3, 40 and 36.7 m asl were submitted for radiocarbon dating but at least three of these samples were clearly in error, ie. much younger than would be expected. These bones were probably contaminated by rootlets or other recent organic material, especially the smaller seal bones (see S-2666 and S-2669, Table 5.1) Furthermore, seal bones can also be transported by mammals and birds and this may also explain these anomalously young dates. Bone samples S-2665 and S-2668 provide similar ages that are in stratigraphic order; ie. 5535 BP at 36.5 m and 5910 BP at 39.9 m asl. Although these dates plot above the envelope shown on Figure 5.5, they may not be incorrect if the marine limit on Russell Island is considerably higher than 108 m (perhaps ca. 160-180 m) and 10,000 to 11,000 BP old (see alternative curve A, Fig. 5.5).

Sample GSC-3999 are paired Astarte borealis valves collected in growth position at 12 m asl from the glaciomarine/marine silts in the western lowland. Although it was hoped that these shells would date marine limit, they are clearly too young (5100 +/- 100 BP) and therefore they likely relate to a sea level somewhere between 20 and 30 m asl (Fig. 5.5).

Prior to 5000 BP the control is not adequate to distinguish between the faster vs. the slower curves whereas after 5000 BP there is better control which suggests one curve for the entire island. The true emergence curve lies within the projected envelope and is equivalent to either slope A or B, Figure 5.5. Because of the close proximity to northwestern Prince of Wales Island, the curve is more likely to be parallel to slope A.

5.6 Regional Variation in the Rate of Emergence

This section compares Russell Island emergence with other sites in the central Arctic, specifically in Baring and Parry Channels.

5.6.1 Northern Prince of Wales Island

Recently Dyke (in press,b and personal communications) has used radiocarbon dates to reconstruct the sea level history of northern Prince of Wales Island. Consequently, the postglacial emergence of Russell Island can be compared with that on the opposite coast of Baring Channel. Figure 5.6 presents the known marine limits and/or uppermost shorelines observed in the area of Russell Island together with their ages. The map includes extrapolated isochrones which show the generalized pattern of ice retreat from 11,000 to 9,500 BP.

Preliminary emergence curves have been produced at four sites on northern Prince of Wales Island: 1) Hollist Point on the west coast; 2) Reliance Bay on the northwest coast; 3) Cape Hardy on southeastern Baring Channel; and 4) Back Bay on the northeast coast (Figures 5.6 and 5.7). These curves and the inferred sea level history of northern Prince of Wales Island are tentative because several significant radiocarbon dates are presently being processed and fieldwork is continuing.

The deglaciation of northern Prince of Wales Island commenced just prior to 11,000 BP. This date was obtained from Hiatella arctica shells collected on the surface of stoney clays on the southwest flank of Donnett Hill, on the distal side of major moraine ridges. The date fits consistently on a preliminary emergence curve, relating to the local marine limit at 188 m

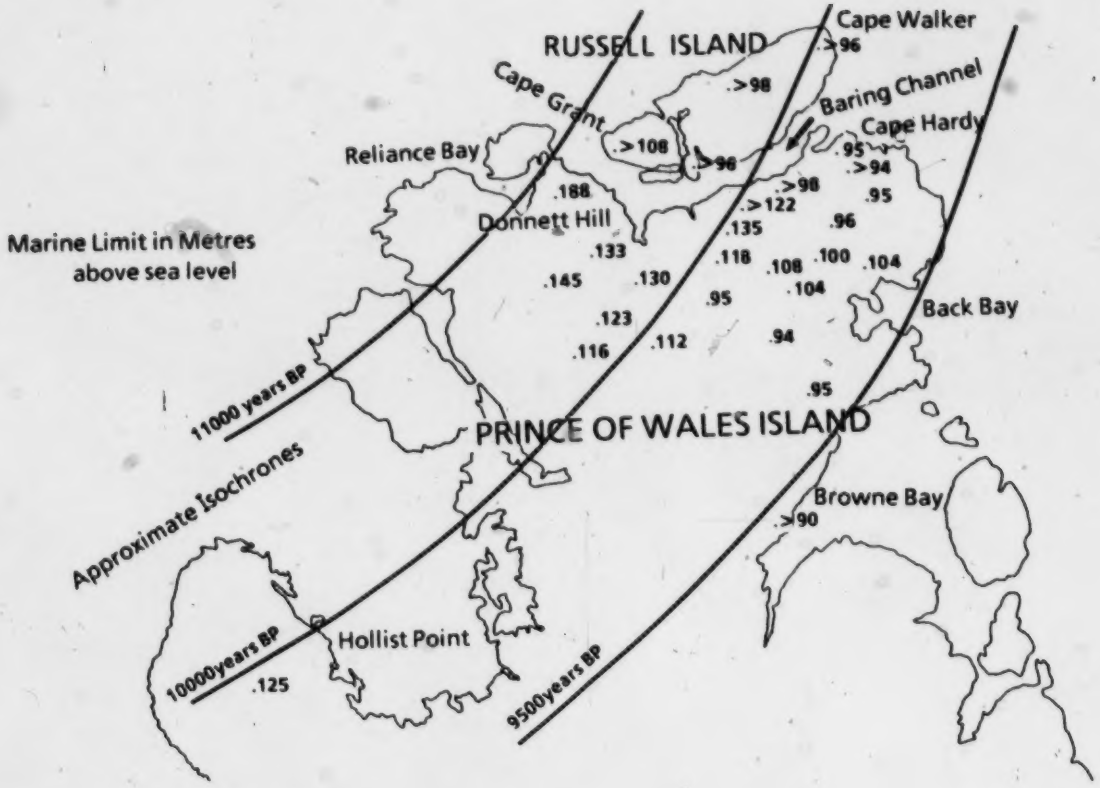


Figure 5.6 Sites of known marine limit and/or uppermost shoreline elevations and ages on Russell Island and northern Prince of Wales Island.

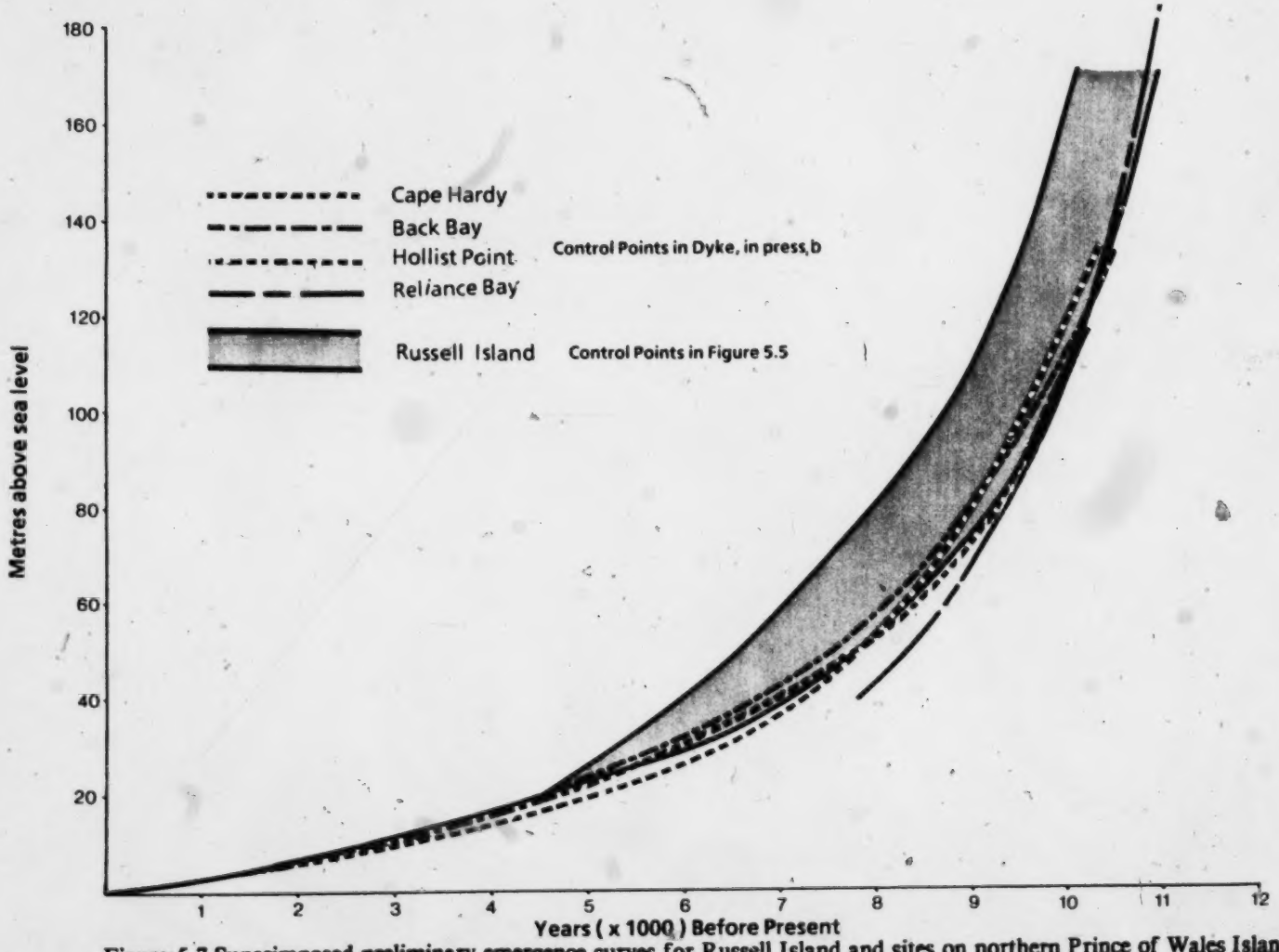


Figure 5.7 Superimposed preliminary emergence curves for Russell Island and sites on northern Prince of Wales Island.

asl. Previous studies indicated that an ice shelf extended across Viscount Melville Sound between 10,300 and 9,800 BP and that Prince of Wales Island was ice-covered during that interval (Hodgson and Vincent, 1984). Implicitly, this new date of 11,000 BP requires a revision of the deglacial chronology and ice configuration. Dyke (in press,b) now brackets the Viscount Melville Sound Ice Shelf between 11,300 BP (the youngest date below the Winter Harbour Till on southern Melville Island) and 11,000 BP (deglaciation of northwest Prince of Wales Island). Dyke explains that such a rapid break-up is consistent with the previous hypothesis that the ice shelf represents a glacial surge (Hodgson and Vincent, 1984).

The regional distribution of marine limit elevations and ages in Figure 5.6 and the arrangement of curves in Figure 5.7 primarily reflect the pattern of ice retreat. Marine limit elevations on northern Prince of Wales Island exhibit a decline from 188 m in Reliance Bay to 95 m in Back Bay. Because the ice retreated towards the southeast, sites of earlier deglaciation in the northwest have higher marine limits. The uppermost shorelines observed on western Russell Island present an anomaly, reaching only 108 m compared to 188 m asl on Donnett Hill, 12 km across Baring Channel (Fig. 5.6). The uppermost shorelines on the north and south coasts of Russell Island appear to be about 40 m lower than expected, hence they are considered to be below the true marine limit. However, the 96 m shoreline on northeastern Russell Island could be considered equivalent to marine limit.

The ice front retreated from Back Bay in the southeast at about 9700 BP. Therefore, marine limits decrease in age from about 11,000 to 9,700 BP from northwest to southeast across northern Prince of Wales Island. This gives an average retreat rate of about 8 km/century.

Due to the dating of the higher, early shorelines, Reliance Bay displays the highest initial emergence rates of 9.8 m/century betwen 11,000 and 10,400 BP. Russell Island appears to lack this rapid initial emergence observed at Reliance Bay. However, if the steeper curve is accepted (Curve A, Fig. 5.5) it indicates that the Russell Island marine limits, formed between 10,000 and 11,000, should be between 160 m and 180 m asl and hence its initial emergence could be similar to that at Reliance Bay. In fact, because both areas had uniform ice thicknesses and

similar dates of deglaciation, their emergence curves should also be similar (Andrews, 1968). Finally, since 7000 BP their curves are closely parallel, hence prior to 7000 BP they should also be similar.

Because much of the recovery was already completed by 7000 BP, Reliance Bay appears to have experienced the lowest rate of emergence at 46 cm/century from 7000 BP to present. On the other hand, Back Bay/Browne Bay had the highest rate of emergence at 61 cm/century since 7000 BP because they were deglaciated more recently. Russell Island emerged at 47 cm/century during the last 7000 years, a rate similar to Reliance Bay during the same period. All the curves from Russell Island to Back Bay, northeast Prince of Wales Island show approximately the same rate of emergence during the last 5000 years. Local differences probably reflect imprecision in drawing the individual curves.

The middle to early Holocene part of the Russell Island emergence curve seems to fall below the curves for Hollist Point and Back Bay, the two sites farthest from Russell Island. This indicates a general southward rise in shorelines of the same age. On the other hand, the Russell Island emergence curve (slope A) appears similar to the curves from the closer sites, Reliance Bay and Cape Hardy. This demonstrates little shoreline tilting (within measurement/dating error bars) between Russell Island and northern Prince of Wales Island.

5.6.2 Central Arctic

This section compares the postglacial emergence of Russell Island to sites in other parts of the central Arctic: Keewatin, Cornwallis Island, Somerset Island and central Melville Island (see Fig. 1.1). Figure 5.8 shows the superimposed emergence curves from these areas which provide a measure of the regional ice loading and sequence of ice retreat.

The central Melville Island emergence curve commences earliest (prior to 11,000 BP) and has the lowest rate. The Keewatin emergence curve is the youngest (9600 to 8800 BP) and displays the highest rate. The Russell Island emergence envelope appears intermediate as would be expected from the position of the island between the glacial limit on Melville Island and the

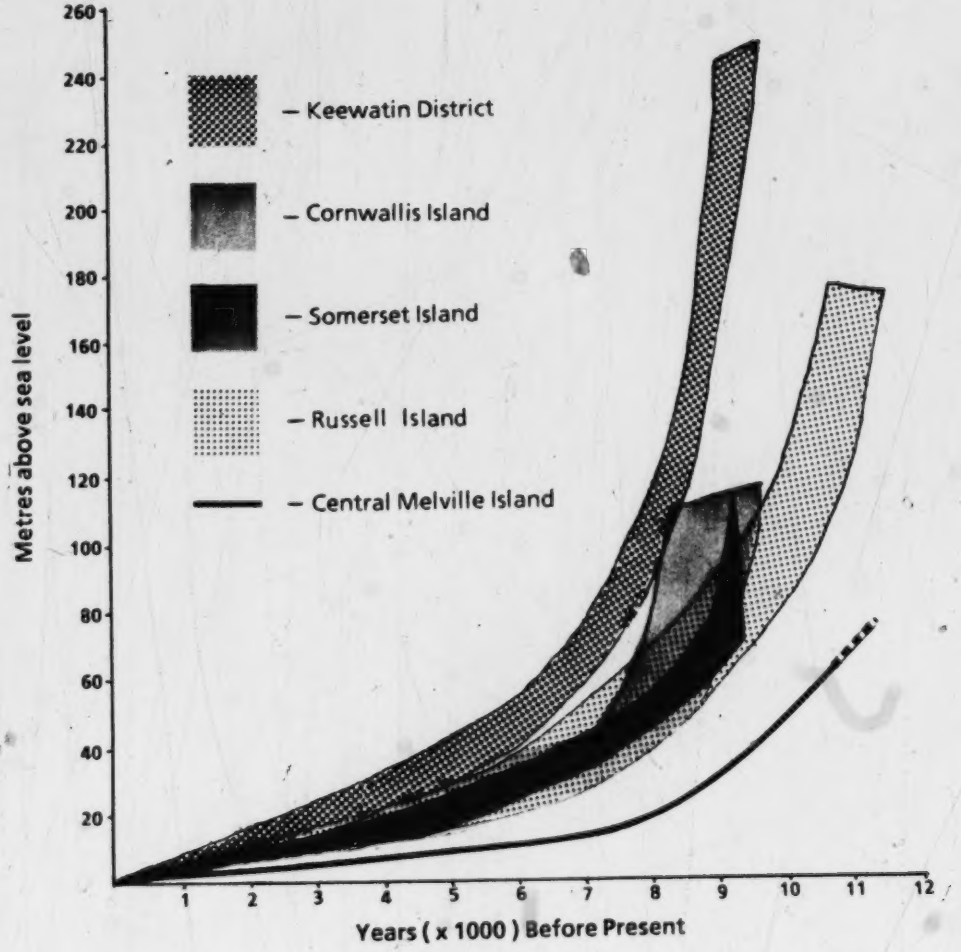


Figure 5.8 Superimposed emergence envelopes from the central Arctic.

late glacial ice over Keewatin (well inside that limit.).

The Somerset Island and Cornwallis Island emergence curves overlap and have similar rates. Preliminary work indicates that the deglaciation of Cornwallis Island began at about 9600 BP (Washburn and Stuiver, 1985) based on dates on shells from raised beaches. These dates were corrected by subtracting 410 years in order to make them comparable with calculations provided by the G.S.C. and Saskatoon laboratories. Ice retreated from Somerset and Cornwallis islands following the deglaciation of Russell Island but before the deglaciation of Keewatin.

The regional configuration of ice (distribution of the ice load) is indicated by the onset of emergence (deglaciation) and the slopes of the various curves. This arrangement of emergence curves primarily reflects greater loading towards the south. Of these sites, Melville Island experienced the least loading by Late Wisconsinan ice because the M'Clintock Dome formed an ice shelf in Viscount Melville Sound from a short-lived surge which grounded against the south shore of the island (Hodgson and Vincent, 1984). Deglaciation commenced earlier on Melville Island because it was in this unstable marginal position. The Keewatin emergence is latest because of its close proximity to a late glacial dispersal centre.

The Somerset Island emergence curve demonstrates the persistence of the eastern margin of the M'Clintock Dome which withdrew from the Gulf of Boothia and from the northern coast of Somerset Island about 9800 BP (Dyke, 1983). The preliminary curves from Cornwallis Island indicate a wide envelope of emergence. Cornwallis Island was probably isostatically influenced by both M'Clintock Ice and Foxe Ice (Dyke, 1984, Fig. 16, p. 20). Some of the emergence could also be due to local, cold-based ice caps on Cornwallis Island and adjacent Queen Elizabeth Islands (Barnett et al., 1976). Details of the glacial history and resulting local patterns of postglacial emergence remain unresolved on Cornwallis Island.

The M'Clintock Dome controlled ice dispersal in the central Arctic between Banks Island to the west and the Gulf of Boothia to the east. Although the centre of maximum M'Clintock ice dispersal lay over M'Clintock Channel, the emergence patterns mapped over northern Prince of Wales Island and Russell Island reflect greater loading to the south and

possibly to the southwest. This indicates that the main centre of the M'Clintock ice load was located in the southern part of M'Clintock Channel, in the vicinity of King William Island (see Fig.1.3).

5.7 Conclusions on Emergence

Based on the projection of shoreline elevations from northern Prince of Wales Island (Figure 5.6), the uppermost shoreline on northeastern Russell Island could represent marine limit. The uppermost shoreline on western Russell Island is considerably lower than might be expected for the local marine limit. Three possible factors might explain this: 1) observational error; 2) tectonic processes; and 3) glacial dynamics.

1)Observational Error: This explanation is based on the possibility that the uppermost shorelines, especially at the west coast (108 m asl) do not record the marine limit. Based on the northward decline in glacial loading, the extrapolated gradient on marine limit from northern Prince of Wales Island suggests that the Russell Island marine limit should be about 170 m in the west and about 110 m in the east. Because of the rapid rate of initial emergence it is possible that the record of the initial marine incursion is unavailable above the uppermost, observed shorelines, especially if there was pervasive, landfast sea ice that prevented the formation of the earliest shorelines. This problem is increased because the subdued topography of western Russell Island restricts the sites where the true marine limit could be recorded. For example, the highest point on western Russell Island is only 170 m asl whereas most of the plateau west of the western lake lies below 120 m asl. Therefore, it is concluded that the present emergence curve for Russell Island is incomplete because of the lack of clear field evidence marking marine limit. The Russell Island emergence curve is very well controlled for the last 5000 years.

2) Tectonic Processes: Stein et al. (1979) have shown that glacioisostatic unloading can produce sufficient stress to reactivate faults. Consequently, it is possible that recent block faulting on Russell Island has lowered marine limits relative to those found on northern Prince of Wales Island. Evidence of postglacial faulting was not found on Russell Island and has not

been reported in the Arctic and therefore it is considered to be an unlikely explanation of the lower shorelines of Russell Island.

3)Glacial Dynamics: This explanation is based on the possibility that the glacial configuration or chronology on Russell Island was different than northern Prince of Wales Island. During deglaciation, a late ice cover on Russell Island would result in lower marine limits because of greater restrained rebound. For example, if ice did remain over western Russell Island until about 10,500 BP, up to 50 m of initial isostatic recovery would have been lost to restrained rebound based on the early emergence rate of about 10 m/century projected from Reliance Bay which began about 11,000 BP. Significant amounts of restrained rebound have been demonstrated to cause unexpected departures in the regional pattern of marine limit in other parts of the Arctic (Blake, 1966; Andrews, 1970; Dyke, 1984). Therefore, this mechanism must be considered in the discussion of the lower shorelines on Russell Island.

Presently, the evidence for or against this reconstruction is equivocal and the oldest C^{14} date available on Russell Island is 9360 +/- 150 BP. Nonetheless, the mapping of late glacial features and striae on Russell Island did not indicate patterns that departed from the regional glacial flows. The early, eastward glacial flows and late glacial north and northwestward flows portrayed on Russell Island have also been mapped over parts of northern Prince of Wales Island (Dyke, personal communication). The dispersal of M'Clintock ice therefore appears to have been relatively uniform over this region and there is no evidence of a residual ice cap which precludes a different history of glacial unloading on Russell Island.

5.7.1 Conclusion

In conclusion, it is likely that postglacial submergence reached above the uppermost shorelines (ca. 100 m asl) observed on Russell Island. Rapid initial emergence coupled with the island's topography likely prevented the formation of the higher shorelines (ca. 170 m asl) and this may have been further hindered by pervasive landfast sea ice during and following deglaciation. The difference between Reliance Bay and western Russell Island may also involve

a certain amount of restrained rebound. Even a delay in deglaciation of 500 to 700 years could explain the loss of 50 to 70 m of observable recovery resulting in lower shorelines (by this amount) on Russell Island.

6. CONCLUSION

This chapter summarizes the late Quaternary history of Russell Island based on the mapping of surficial features; the analyses of till composition and the envelope of postglacial emergence. The reconstruction also builds upon previous and on-going studies on the Quaternary geology of adjacent islands. The last section of the chapter recommends a strategy for further research.

6.1 Sequence of Events

This section presents the sequence of late Quaternary events on Russell Island in order of their relative ages.

6.1.1 Early Quaternary Glaciations

Although the number and chronology of glaciations remain provisional, it is known that ice advanced across the central Arctic on several occasions during the Quaternary Period (Dyke, 1983; Andrews et al., 1984). Sections of Quaternary sediments on both Banks Island (Vincent, 1982) and Melville Island (Hodgson et al., 1984) record at least three distinct regional glaciations, the last of which was the late Wisconsinan. All the tills exhibit a mainland provenance which suggests that the glaciers also crossed Russell Island which would have lain in their path of flow towards the north. Unfortunately, fieldwork on Russell Island did not uncover similar sections of Quaternary sediments.

The widespread dispersal of crystalline erratics by early Quaternary glaciations across the central Arctic was noted by Netterville et al. (1976), Barnett et al. (1976) and Dyke (1983, 1984). The northward dispersal of crystalline erractics is also noted by this study. In the eastern part of Russell Island, most of the cobble to pebble sized erratics found within the till samples are derived from the Peel Sound conglomerate. A minority of these erratics are very well altered in shape and suggest a source beyond the conglomerate bedrock. However, none of these smaller sized erratics were found in the western till samples. Nonetheless, large boulders up to 2

m^3 in size are common on Russell Island and are clearly incompatable with the size range of crystalline clasts in the conglomerate. The widespread occurrence of these large granitic and gneissic erratics provides evidence for northward incursions of continental ice during glaciations prior to the Late Wisconsinan, when ice extended to Banks and Melville islands. Subsequently, the erratics could have been re-incorporated and dispersed by any number of later ice flows.

6.1.2 Late Wisconsin Maximum

By compiling surficial maps and dates of deglaciation Dyke (1984) demonstrated that between 18,000 and 11,500 BP, a northward extension of Laurentide Ice led to the establishment of a dispersal axis over M'Clintock Channel. At the height of the late Wisconsin glaciation, the M'Clintock Ice Divide dictated the major ice flow patterns in the central Arctic.

This study corroborates many of Dyke's (1984) conclusions indicating that the oldest bedrock striae record the spread of ice eastward over Russell Island from M'Clintock Channel during the late Wisconsin glacial maximum. The mapping of till compositions revealed that the early, eastward flow was stronger and of greater duration than the later deglacial flows. This sustained, eastward flow transported fine-grained material derived from the western carbonate bedrock completely across Russell Island. Textural, carbonate and trace element analyses showed that some tills from the eastern uplands are the product of this earlier, eastward flow which were not reworked by the deglacial flows.

6.1.3 Deglacial Flows

At about 11,300 BP, deglaciation commenced in the central Arctic. The Viscount Melville Ice Shelf broke up and the M'Clintock ice retreated towards Keewatin District (Dyke, in press,b). As the ice front rapidly calved into the sea, the balance of the M'Clintock Dome shifted. The cross-cutting bedrock striae on Russell Island indicate that during deglaciation the dispersal centre of M'Clintock ice first migrated eastwards across Prince of Wales Island then retreated southeastwards (Figures 6.1;6.2;6.3;6.4).

Figure 6.1 Ice flow pattern on Russell Island during full glacial and early deglacial time. The centre of ice dispersal shifts eastward from M'Clintock Channel to Peel Sound during the period between 11,300 and 10,800 BP.

Figure 6.2 Approximate ice front position on Russell Island at about 10,800 BP.Arrows indicate flow direction.

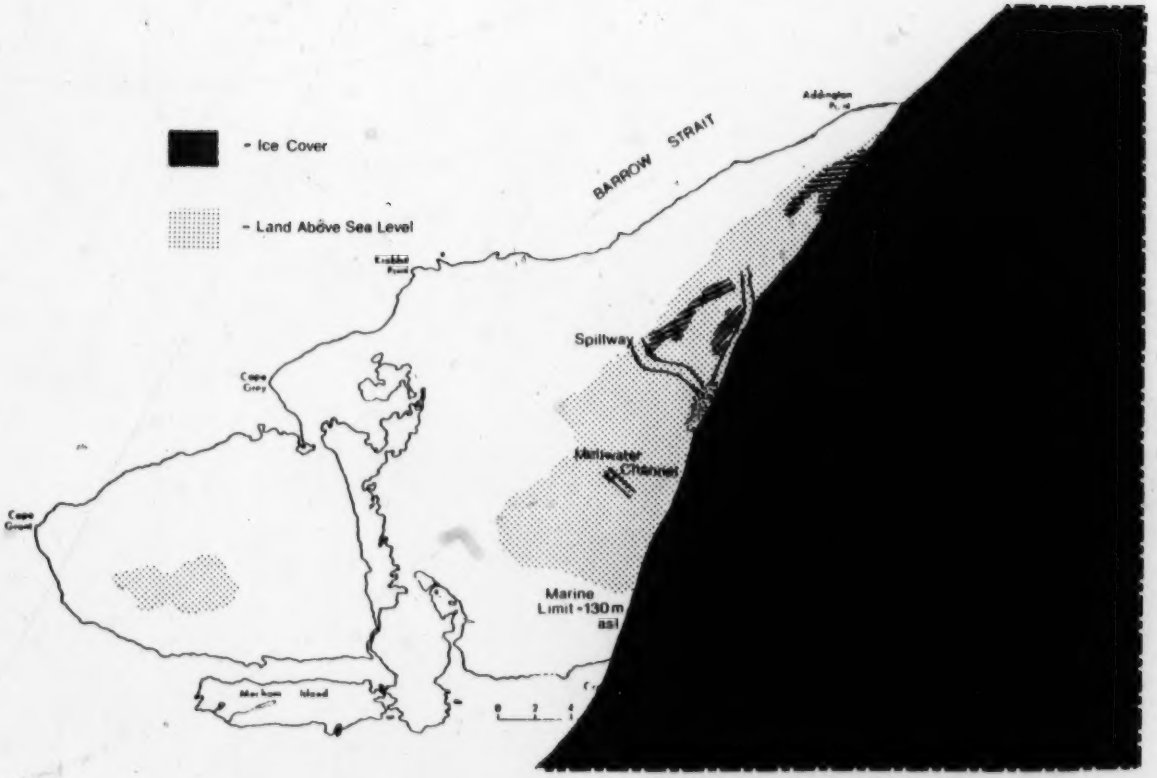


Figure 6.3 Approximate ice front position on Russell Island at about 10,100 BP. Arrows indicate flow direction.

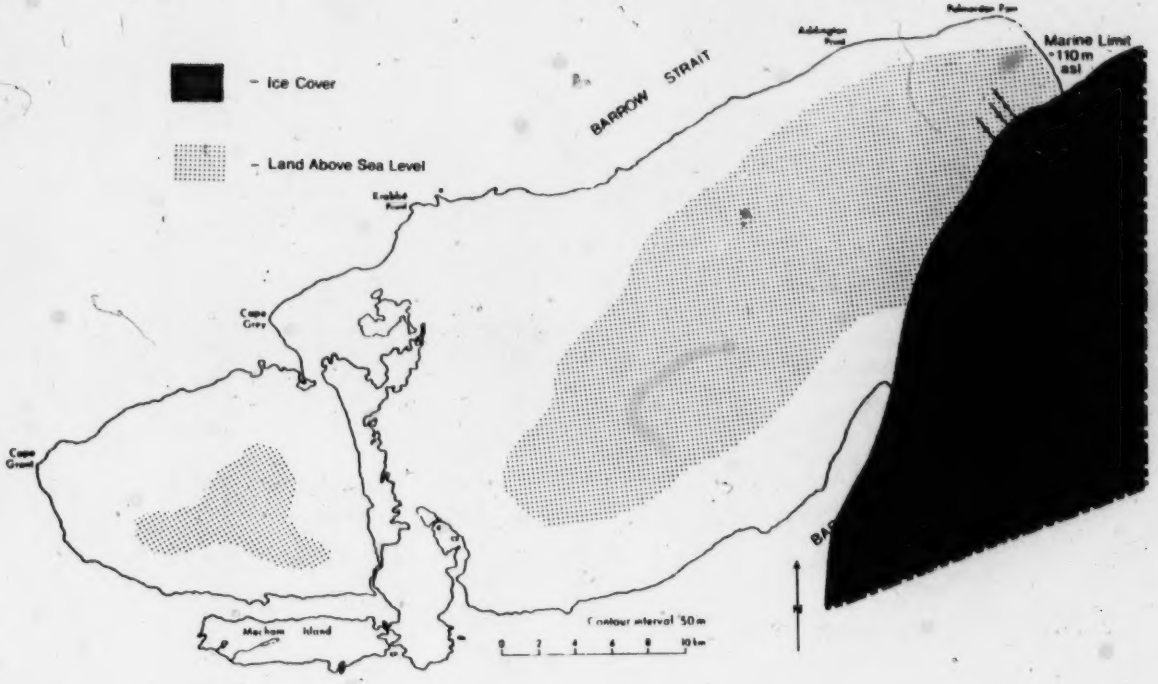


Figure 6.4 Approximate ice front position on Russell Island at about 9,900 BP. Arrows indicate flow direction.

The deglacial flows removed former unconsolidated features; reworked and redeposited sediments; and upon retreat, constructed the main surficial feaures presently observed on Russell Island. A northwestward deglacial flow originating from Peel Sound was particularly erosive, forming roches moutonneés and till flutings on the eastern uplands. The mapping of till compositions suggests that the deglacial flows were relatively short-lived. This resulted in the smearing of coarser, non-calcareous material, dominantly derived from eastern clastic bedrock, towards the northwest. Nevertheless, this deglacial flow did not mask the evidence of the finer grained, calcareous material previously transported from the western part of the island.

Between ca. 10,800 and 9,900 BP, marine limits formed as the ice front retreated towards the southeast at an average of 4 km/century (See Figures 6.2, 6.3 and 6.4). This retreat produced the ice marginal features described in Chapter Four. At present the oldest date on the initial entry of the sea (deglaciation) on Russell Island is 9360 +/- 150 BP.

6.1.4 The Postglacial Period

Glacioisostatic emergence was initiated from west to east, corresponding with the sequence of deglaciation on Russell Island. The uppermost shorelines observed on Russell Island were lower (108 m to 96 m asl) than expected (160 m to 180 m asl). It is likely that a combination of both observational errors (ie. the unavailability of marine limit shorelines) together with restrained rebound can account for the failure to document rapid rates of initial emergence. At least 50 percent of Russell Island was covered by the postglacial sea (with a marine limit of ca. 170 m asl) and more than 20 percent of its surface consists of raised marine sediments.

Throughout the Holocene, permafrost and its associated landforms became progressively established. The most active periglacial processes include: 1) rock slides and scree formation at the east coast cliffs; 2) frost shattering of exposed carbonate bedrock; 3) solifluction of weathered bedrock and beach sediments; and 4) cryoturbation of fine-grained

tills. Another dominant process active during the Holocene is the formation of alluvial deposits in river valleys (as fans and plains). There is little geomorphic evidence of climatic fluctuations during the Holocene, except for the apparent abundance of driftwood on raised beaches below 15 m asl. This suggests that forests have become better established in boreal areas during the past 4000 years and that sea ice cover has been less severe during the same interval (cf. Blake, 1972).

6.2 Further Research

Constraints on time during the fieldwork inevitably result in some observations being preliminary or speculative. Consequently, there is always the need to refine the data base. Most importantly, the elevations on the uppermost shorelines are much lower than expected for Russell Island and this problem remains unresolved. Another, related objective for future research would be to obtain additional radiocarbon dates on the initial entry of the sea, hence deglaciation. This would involve a more intensive search of the raised marine sediments for in-situ shells or whale bone. Greater control on the upper part of the emergence curve is therefore emphasized. Efforts should also be made to provide better control on the late Holocene part of the emergence curve particularly given the abundance of driftwood on beaches below 15 m asl. This would provide a better context for evaluating differential, postglacial emergence in the central Arctic. Finally, further comparisons with other on-going research projects on northern Prince of Wales Island should provide new insights or alternative interpretations to those made in this study.

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LEGEND

SURFICIAL DEPOSITS

QUATERNARY

POST-LAST GLACIATION
NON-GLACIAL ENVIRONMENT

FLUVIAL SEDIMENTS: gravel and sand 2-20m thick, deposited on floodplains

Af Ap	Seasonally flooded sediments
At	Terraced sediments above present flood zone

MARINE SEDIMENTS: gravel, sand, silt and clay, 1-20m thick, deposited in deltaic and beach environments during regression of the post-glacial sea.

Mr	Beach sediments:	gravel and sand, 1-5m thick, forming ridges and swales.
Mt	Deltaic sediments:	coarsening upward sequences of clay, silt, sand and gravel, 5-20m thick, with flat, terraced, or dissected surfaces.

LAST GLACIATION
PRO-GLACIAL AND GLACIAL ENVIRONMENT

GLACIOMARINE SEDIMENTS: clay, silt, sand and gravel, 1-100m thick, deposited in nearshore environments while the sea was at or near marine limit, not differentiated from postglacial marine nearshore sediments.

fMv fMb	Nearshore sediments:	silt, clay silt and fine sand, veneer at <2m thick and blanket at 2-100m thick, with flat, highly dissected, or gullied surfaces.

GLACIOFLUVIAL SEDIMENTS: gravel and sand, 1-100m thick, deposited behind, at, and in front of the ice margin.

Gf Gp	Proglacial outwash:	gravel and sand, 1-10m thick, deposited on floodplains
Ih It	Kames:	gravel and sand, 10-100m thick, forming conical hills, ridges and terraces.

GLACIAL ENVIRONMENT

TILL: non-sorted debris, 0.5-20m thick

Tv	Till veneer:	<2m thick and discontinuous, surface mimics form of underlying rock surface.
Tb	Till blanket:	2-40m thick, gently rolling surface often with kettle depressions.

BEDROCK

PRE-QUATERNARY

ROCK: rock of various lithologies and ages; hilly and hummocky with basins, very bouldery terrain, cliffs and ice moulded forms produced by glacial scouring; includes numerous patches of thin till.

R	Consolidated: Sedimentary Rocks	conglomerate/sandstone in the east and limestone/dolomite in the west, middle Paleozoic age; surface often frost shattered.

Cliff in bedrock

Emily Bay
Donnett Hill
660
600
535+
Arabella Bay
Cape Grant
Cape Grey
Krabbé Point
Mecham Island
Forsyth Pt
Forsyth
RUSSELL
ISLAND
ARING
CHANNEL
400
470
150
700
770+
670+
500
100

Krabbé Point

Cape Grey

Addington Point

Palmerston Point

Cape Walker

RUSSELL ISLAND

CHANNEL

Bell

Scale 1:125,000

0 5 10 Km

N

		swales.
Mt	Deltaic sediments:	coarsening upward sequences of clay, silt, sand and gravel, 5-20m thick, with flat, terraced, or dissected surfaces.

LAST GLACIATION
PRO-GLACIAL AND GLACIAL ENVIRONMENT

GLACIOMARINE SEDIMENTS:		clay, silt, sand and gravel, 1-100m thick, deposited in nearshore environments while the sea was at or near marine limit, not differentiated from postglacial marine nearshore sediments.
fMv fMb	Nearshore sediments:	silt, clay silt and fine sand, veneer at <2m thick and blanket at 2-100m thick, with flat, highly dissected, or gullied surfaces.
GLACIOFLUVIAL SEDIMENTS:		gravel and sand, 1-100m thick, deposited behind, at, and in front of the ice margin.
Gf Gp	Proglacial outwash:	gravel and sand, 1-10m thick, deposited on floodplains
Ih It	Kames:	gravel and sand, 10-100m thick, forming conical hills, ridges and terraces.

GLACIAL ENVIRONMENT

TILL:		non-sorted debris, 0.5-20m thick
Tv	Till veneer:	<2m thick and discontinuous, surface mimics form of underlying rock surface.
Tb	Till blanket:	2-40m thick, gently rolling surface often with kettle depressions.

BEDROCK

PRE-QUATERNARY

ROCK:		rock of various lithologies and ages; hilly and hummocky with basins, very bouldery terrain, cliffs and ice moulded forms produced by glacial scouring; includes numerous patches of thin till.
R	Consolidated: Sedimentary Rocks	conglomerate/sandstone in the east and limestone/dolomite in the west, middle Paleozoic age; surface often frost shattered.

Cliff in bedrock

Bedrock striae(ice flow direction)

Ice moulded bedrock
(crag and tail, roche moutonnee)

Fluting in till

End moraine ridge

Esker (direction of flow)

Kame

Meltwater channels
subglacial
spillway

Marine Limit

Landslide

Till patches on bedrock